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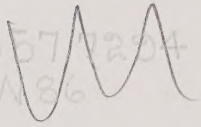
GEOLOGICAL SURVEY OF THE REPUBLIC OF HAITI
WENDELL P. WOODRING, Geologist in Charge

GEOLOGY OF THE REPUBLIC OF HAITI

BY

WENDELL P. WOODRING, JOHN S. BROWN
AND WILBUR S. BURBANK

PORT-AU-PRINCE
1924



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GEOLOGY OF THE REPUBLIC OF HAITI.

By Wendell P. Woodring, John S. Brown, and Wilbur S. Burbank.

INTRODUCTION.

By Wendell P. Woodring.

ARRANGEMENTS FOR THE RECONNAISSANCE.

On March 24, 1917, Hon. Frank L. Polk, Acting Secretary of State of the United States, addressed a letter to Hon. Franklin K. Lane, Secretary of the Interior, calling attention to Article I of the treaty of September 16, 1915, between the United States and the Republic of Haiti, which provides that the Government of the United States will by its good offices aid the Haitian Government in the proper and efficient development of its agricultural, mineral, and commercial resources, and inquired whether it would be practicable for the United States Geological Survey to make a geological reconnaissance of the Republic of Haiti. In reply the Secretary of the Interior stated that the Geological Survey would cooperate by furnishing the scientific personnel, but that it had no authority under which any part of the appropriations made by Congress for its maintenance could be expended outside the territorial limits of the United States. In later correspondence estimates of the expenditures necessary for a geological reconnaissance were submitted by the Secretary of the Interior.

In the summer of 1919 plans for the reconnaissance submitted by the Director of the United States Geological Survey were approved by the Secretary of State for Public Works of the Republic of Haiti and by Hon. John A. McIlhenny, Financial Adviser to the Haitian Government, and Commander E. R. Gayler, C. E. C., U. S. N., Engineer in Chief of the Department of Public Works.

In the meantime field work had been begun for a geological reconnaissance of the Dominican Republic under the supervision of the United States Geological Survey. Dr. T. W. Vaughan, of the United States Geological Survey, who was in charge of the work in the Dominican Republic, made an inspection trip from Ouanaminthe to Port-au-Prince and return in order to make more effective plans for the field work in the Republic of Haiti.

The appropriation for the reconnaissance was made by the Council of State. The field work was delayed until the fall of 1920 in order that all

the information contained in the complete report on the geology of the Dominican Republic might be used to the greatest advantage. The final arrangements for the work were made with Commander A. L. Parsons, C. E. C., U. S. N., who succeeded Commander Gayler as Engineer in Chief.

FIELD WORK.

Messrs. John S. Brown, Wilbur S. Burbank, Frank G. Evans, jr., and I arrived in Port-au-Prince on October 1, 1920. We spent the succeeding six and a half months in the field and sailed from Port-au-Prince on April 15, 1921. During most of the time we spent in the field we worked in two parties, traveling by automobile, on horseback, and on foot along the routes shown in Plate III and mapping the geology as we traveled, thus making a reconnaissance survey of almost the entire Republic, including Gonave and Tortue islands. General geologic work was done by all the members of the expedition, but Mr. Brown gave particular attention to the underground-water resources and to the field relations of the mineral deposits and igneous rocks, Mr. Burbank examined the mineral deposits and the igneous rocks, and I studied the stratigraphy and stratigraphic paleontology and the lignite and oil resources.

A detailed reconnaissance of several regions was made in order to ascertain the extent of the mineral deposits and the possibility of utilizing the underground-water resources. We had no adequate base map. The triangulation, which was under the supervision of Mr. Glenn S. Smith, of the United States Geological Survey, designed to provide a base for a topographic survey of the Republic, had not progressed far enough to permit us to utilize the results. We used the charts of the Hydrographic Office of the United States Navy for mapping regions near the coast, and we used also the maps of M. L. Gentil Tippenhauer, of Port-au-Prince, which cover some parts of the Republic. In other regions we were forced to rely on rough notebook sketches, in which distances were estimated only by the time consumed in traveling. Unless otherwise stated, altitudes are based on aneroid readings.

While we were in the field Mr. Brown prepared and submitted reports on the public water supply of Port-au-Prince and of Cap-Haïtien. We also prepared a report suggesting improvements in the water supply of some towns and villages, particularly those that now depend on salty water for their principal supply. These preliminary reports have been amplified and included in this volume.

OFFICE WORK.

As soon as we returned to Washington we began to write the text of this report, to examine the collections, and to prepare maps and other illustrations. The original agreement provided that the collections should be deposited in the United States National Museum, but that if a national

museum should be established at Port-au-Prince a duplicate set would be sent there.

The extensive collections of fossils were examined by the following paleontologists: Corals, Dr. T. W. Vaughan, of the United States Geological Survey; Crinoidea, Dr. Frank Springer, of the United States National Museum; Echini, Dr. R. T. Jackson, of Peterborough, New Hampshire; Bryozoa, Dr. R. S. Bassler, of the United States National Museum; Cretaceous Mollusca, Dr. T. W. Stanton, of the United States Geological Survey; Cirripedia, Dr. H. A. Pilsbry, of the Philadelphia Academy of Natural Sciences; decapod Crustacea, Dr. Mary J. Rathbun, of the United States National Museum; fish, Prof. T. D. A. Cockerell, of the University of Colorado; birds, Dr. Alexander Wetmore, of the Biological Survey, United States Department of Agriculture; mammals, Mr. G. S. Miller, jr., of the United States National Museum; plants, Prof. E. W. Berry, of Johns Hopkins University. I undertook the examination of the larger Foraminifera, and in collaboration with Mr. W. C. Mansfield, of the United States Geological Survey, the examination of the Tertiary and Quaternary Mollusca and Brachiopoda. The smaller Foraminifera and several collections of ostracods and calcareous algae have not been examined.

Chemical analyses of igneous rocks were made by Dr. H. S. Washington, of the Carnegie Institution of Washington. Samples of ore and of raw material for cement were analyzed in the chemical laboratory of the United States Geological Survey under the direction of Mr. George Steiger, chief chemist. Other samples of ore were analyzed and assayed by Ledoux & Co., of New York. Mr. E. V. Shannon, of the United States National Museum, analyzed a sample of kaolinite. Samples of lignite were analyzed at the Pittsburgh Laboratory of the United States Bureau of Mines. Samples of rock and other road material, and samples of sand and gravel for making concrete were tested by the Bureau of Public Roads, United States Department of Agriculture. Samples of clay for making brick were tested at the ceramic station of the United States Bureau of Mines at Columbus, Ohio. Analyses of guano were made by the United States Department of Agriculture. Analyses of samples of water were made in the water-resources laboratory of the Geological Survey under the direction of Mr. W. D. Collins.

A preliminary account of the possible oil resources of the Central Plain was published in July, 1922. A brief summary of the results of the reconnaissance was published in the Journal of the Washington Academy of Sciences in April, 1923. These and other papers describing collections obtained during the reconnaissance or setting forth some of its results are listed below:

Berry, E. W., Tertiary fossil plants from the Republic of Haiti: U. S. Nat. Mus. Proc., vol. 62, art. 14, 10 pp., 1 pl, 2 text figs., 1922.

Cockerell, T. D. A., A fossil cichlid fish from the Republic of Haiti: U. S. Nat. Mus. Proc., vol. 63, art. 7, 2 pp., 1 pl., 1923.

Miller, G. S., jr., Remains of mammals from caves in the Republic of Haiti: Smithsonian Misc. Coll., vol. 74, No. 3, 8 pp., 1922.

Pilsbry, H. A., Miocene Cirripedia from the Republic of Haiti: U. S. Nat. Mus. Proc. (Awaiting publication.)

Rathbun, M. J., Fossil crabs from the Republic of Haiti: U. S. Nat. Mus. Proc., vol. 63, art. 9, 6 pp., 2 pls., 1923.

Springer, Frank, A new Tertiary crinoid in the West Indies: U. S. Nat. Mus. Proc. (Awaiting publication.)

Wetmore, Alexander, Remains of birds from caves in the Republic of Haiti: Smithsonian Misc. Coll., vol. 74, No. 4, 4 pp., 2 text figs., 1922.

Woodring, W. P., Middle Eocene Foraminifera of the genus *Dictyoconus* from the Republic of Haiti: Washington Acad. Sci. Jour., vol. 12, pp. 244-247, 1922.

——— Stratigraphy, structure, and possible oil resources of the Miocene rocks of the Central Plain: Republic of Haiti Geol. Survey, 19 pp., map, 1922.

——— Tectonic features of the Republic of Haiti and their bearing on the geologic history of the West Indies (abstract): Washington Acad. Sci. Jour. (Awaiting publication.)

——— An outline of the results of a geological reconnaissance of the Republic of Haiti: Washington Acad. Sci. Jour., vol. 13, pp. 117-129, 1923.

——— Tertiary mollusks of the genus *Orthaulax* from the Republic of Haiti, Porto Rico, and Cuba: U. S. Nat. Mus. Proc.: vol. 64, art. 1, 12 pp., 2 pls., 1923.

ACKNOWLEDGMENTS.

In the field work and in the preparation of the report we have had the unfailing support and encouragement of Commander Parsons, under whose direction the work was done. The field work and most of the office work was done under the supervision of Dr. T. W. Vaughan while he was chief of the sections of Coastal Plains investigations and of West Indian Geological Surveys of the United States Geological Survey. Doctor Vaughan has reviewed the entire report, and we have thus had the advantage of his wide knowledge of the geology of the West Indies and regions near by. We wish to record our deep appreciation of the services of Rev. J. Scherer, Directeur de l'Observatoire Météorologique du Séminaire-Collège St.-Martial. In an unassuming way and almost without the knowledge of the general scientific world he has for years been collecting and publishing invaluable meteorological and seismological data. The matter on climate and earthquakes in this report could not have been written without M. Scherer's records. We have used with great advantage the published geologic maps of M. L. Gentil Tippenhauer, of Port-au-Prince. Only those who have traversed the rugged mountains of the Republic can appreciate the labor that these maps represent. Mr. E. L. McNair, in charge of the triangulation party, and the engineers of the Department of Public Works cooperated with us in every way. Mr. R. A. Conard, engineer of the Haytian-American Sugar Co., furnished logs of wells in the Cul-de-Sac Plain and other information concerning them. Mr. Frank G. Evans, jr., one of the members of the party, gave valuable

help in traversing the country and in making geologic examinations. Dr. W. F. Jones, of the Massachusetts Institute of Technology, gave us the advantage of the results of his work in the Republic in 1918. Many others aided us in different ways. We often enjoyed the hospitality of the parish priests and of the officers and men of the United States Marine Corps and of the Gendarmerie d'Haiti. Everywhere we were received with unfailing cordiality, and we will long remember our pleasant experiences.

Several geologists of the United States Geological Survey have reviewed parts of this report. Mr. E. S. Larsen, jr., reviewed the descriptions of the igneous rocks; Mr. H. G. Ferguson and Mr. D. F. Hewett the descriptions of the mineral deposits; and Mr. N. C. Grover, Mr. O. E. Meinzer, and Mr. W. D. Collins the matter on the water resources.

The titles of the illustrations were edited by Mr. F. E. Matthes, of the United States Geological Survey. The text was translated into French by Mr. M. C. Delporte, and the translation was edited by Mr. J. J. de Gryse. The illustrations were drafted by Mr. Lewis B. Pusey, of the United States Geological Survey.

Part I. GEOGRAPHY.

By John S. Brown and Wendell P. Woodring.

PHYSICAL GEOGRAPHY.

GENERAL RELATIONS.

The most striking thing in the morphology of the West Indies is the arrangement of its geographic features in arcs. Most of the arcs are convex northward, but in Haiti and in islands farther east some of them are convex southward. These arcs, which are seen in the trend of the islands, of the mountain ranges on the islands, and of the ridges and troughs in the submerged areas, are shown in Figure 1, a map based on one recently published by Professor Taber,[1] to whom we are indebted for its use.

The island of Haiti, the largest of the West Indian islands except Cuba, is between Cuba and Porto Rico. It lies between parallels 17° 39′ and 20° north latitude, and meridians 68° 20′ and 74° 30′ west of Greenwich. The Atlantic Ocean borders it on the north and the Caribbean Sea on the south. It is separated from Cuba by the Windward Passage and from Porto Rico by the Mona Passage. The submerged platform in the Mona Passage is relatively shallow, the maximum depth of water in the central part being but 260 fathoms (475 meters). The Bartlett Deep, the most remarkable of the deep troughs of the West Indies, extends into the Windward Passage, where the floor of the sea plunges southwestward from a depth of 893 fathoms (1,633 meters) to 1,737 fathoms (3,177 meters). A submerged ridge extends westward from the southern peninsula of the Republic of Haiti beyond the eastern end of a similar ridge that extends westward from Jamaica. These two ridges are separated by a trough having a maximum depth of 1,573 fathoms (2,877 meters). Between the island of Haiti and the Bahama Banks is an unnamed trough having a maximum depth of 2,388 fathoms (4,367 meters). South of the island lies the deep basin of the Caribbean Sea.

The Republic of Haiti occupies approximately the western third of the island and the Dominican Republic the eastern two-thirds. The maximum length of the Republic of Haiti is about 295 kilometers, and its width near the Dominican border is about 183 kilometers. The area of the

[1] Taber, Stephen, The great fault troughs of the Antilles: Jour. Geology, vol. 30, pp. 89-114, pl. 1, fig. 6, 1922.

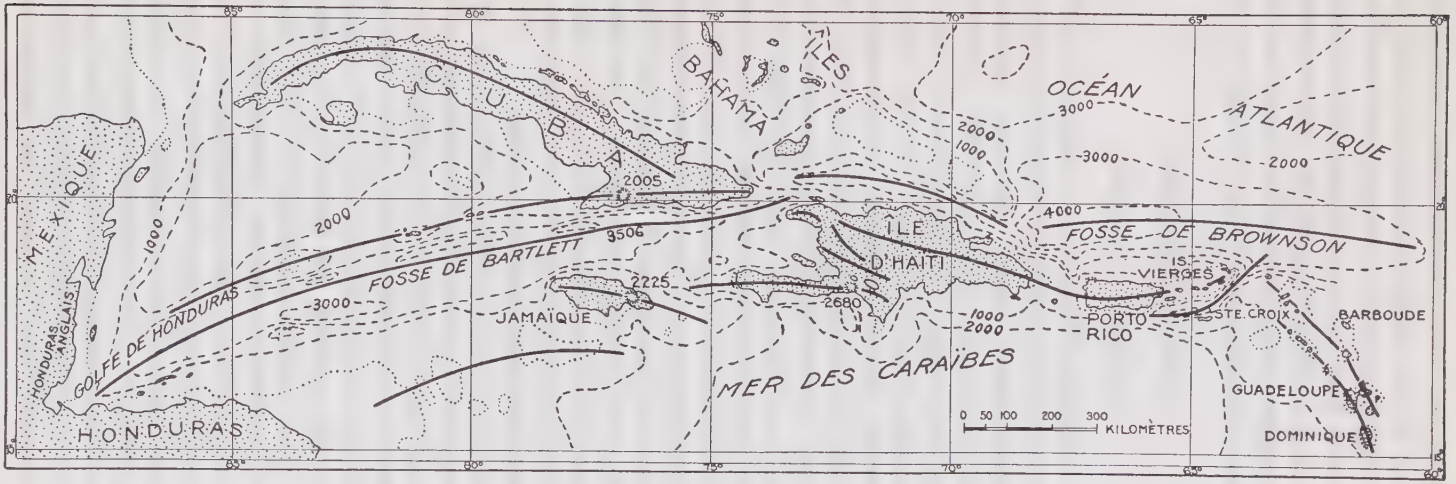


FIGURE 1.—Map showing trend of geographic features of the West Indies.

Base from Taber. Contour interval 1,000 fathoms (1,829 meters). Areas within dotted lines less than 100 fathoms (183 meters).

Republic, including Tortue Island, Gonave Island, Grande Cayemite, and Ile à Vache, is about 27,700 square kilometers, according to planimeter measurements of a map compiled by the Service des Levés Topographique. The precise area of the Republic is not known, as the boundary between the two Republics has not been definitely fixed. The two prominent westward-extending peninsulas, the northwest peninsula and the southern peninsula, embrace an extensive body of water in which lies Gonave Island.

SURFACE FEATURES.

General Character.

Haiti is very mountainous. Towering mountains are visible from the sea in front of any of the open ports of the Republic, and at many ports steep mountain slopes extend down to the coast. The traveler who is accustomed to wide plains can scarcely believe that a population so large as that of the Republic can live in a country so rugged, yet the exports from which the Republic largely derives its revenue consist principally of agricultural products. The ruggedness of the mountains is even more impressive to one who travels along the trails that extend into the heart of all the mountains. The mountain slopes at moderate altitudes yield immense crops of coffee, which forms the leading article of export. The mountain slopes at all altitudes are cultivated in small gardens, which yield the vegetables and fruits that are sold at innumerable market places, which form the most characteristic feature of the commercial and social life of the rural districts. Large areas of the plains that flank the mountains in some parts of the Republic are semiarid. The rural population is concentrated in the fertile mountain valleys and in the parts of the plains that through natural heavy rainfall or the application of water by irrigation yield sugar cane, cotton, and other crops.

Although a large part of the Republic is mountainous, extensive plains flank the mountains at some places along the coast or extend like wedges into the mountainous regions. Many of the mountains consist of beds of limestone, and steep slopes that are scarred by high cliffs form the most characteristic feature of these mountains. These cliffs appear to be abnormal features; they were probably not formed by the usual processes of subaerial erosion. They are confined almost entirely to regions where the limestone is massive, regardless of its age. The base of the cliffs is determined by the outcrop of strata of thin-bedded limestone or other kinds of rocks. The cliffs have apparently been formed by the undermining and subsequent stoping of blocks of massive limestone by ground water, which has penetrated the rock and percolated along the contact with the underlying beds. The contrast between the surface features produced by the erosion of massive and of thin-bedded limestone is clearly shown on the north and south slopes of Mont Puilboreau, the limestone range between

Ennery and Plaisance. The massive limestone on the north slope is scarred by cliffs that attain a height of several hundred meters. On the south slope, where the limestone is thin-bedded, the dissection is more intricate and there are no cliffs.

Geographic Provinces.

The following geographic provinces are recognized in this report. The boundaries between these provinces are shown approximately on Plate XXVII, page 354.

Tortue Island.
North Plain.
Massif du Nord.
Northwest Peninsula.
Central Plain.
Montagnes Noires.
Artibonite Plain and Valley.
Montagnes du Trou d'Eau.
Chaîne des Mateux.
Cul-de-Sac Plain.
Massif de la Selle.
Massif de la Hotte.
Gonave Island.

As the topographic features of these provinces are determined by the physical and structural features of their surface rocks and by their geologic history they are fully described in Part III, which follows the text describing the stratigraphic and structural geology and the geologic history. The surface features are briefly summarized here in order to furnish the geographic setting for the description of the geology.

Tortue Island is an imperfectly dissected plateau, the margins of which are modified by late emergence.

The North Plain extends along the north coast from Acul Bay eastward to the Dominican border. Between Acul Bay and Cap-Haïtien the plain is shut off from the sea by Morne du Cap, an outlier of the Massif du Nord.

The Massif du Nord, which is the northwestern prolongation of the Cordillera Central of the Dominican Republic, extends from the Dominican border northwestward to the deep trough of the valleys of Rivière la Quinte and Les Trois Rivières north of Gros-Morne. The Massif du Nord forms the western part of the arc that extends across the island. The entire massif is mountainous and very rugged.

The Northwest Peninsula embraces the entire peninsula west of the valleys of Rivière la Quinte and Les Trois Rivières. This region contains a variety of surface features, including mountains, lowlands, and an extensive plateau, as follows: Montagnes de Terre-Neuve, Montagnes du Nord-ouest, Arbre Plain, Jean Rabel Valley, Bombardopolis Plateau. The Montagnes du Nord-ouest and the Montagnes de Terre-Neuve form a short arc that is convex northward. The most striking features of the peninsula are the magnificent emerged terraces that border the outer margins of the Bombardopolis Plateau.

The Central Plain, which is the only extensive interior plain in the Republic, extends from the Dominican border northwestward to St.-

Michel de l'Atalaye as a wedge between the Massif du Nord and the Montagnes Noires. It is the northwestward prolongation of the San Juan Valley of the Dominican Republic.

The Montagnes Noires form a mountain system that is the northwestern prolongation of the northern part of the Sierra de Neiba of the Dominican Republic. At its northwest end it merges into the Massif du Nord forming a short arc that is convex southward.

The Artibonite Plain is a wedge extending southeastward between the Montagnes Noires and the Chaîne des Mateux together with the Montagnes du Trou d' Eau. The apex of the wedge is near the Dominican border, where the Montagnes Noires join the Montagnes du Trou d'Eau. The southeastern part of the Artibonite Plain, to which the name Artibonite Valley is applied, has a greater variety of surface features than the northwestern part—the plain proper. Morne Grammont is an isolated outlier of the Montagnes Noires in the plain southeast of Gonaïves.

The Chaîne des Mateux and its southeastward prolongation, the Montagnes du Trou d'Eau, extend southeastward from St.-Marc to the Dominican border as an arc that is convex southward and form the prolongation of the southern part of the Sierra de Neiba of the Dominican Republic.

The Cul-de-Sac Plain is part of a remarkable depression that extends across the island from Port-au-Prince Bay to Neiba Bay. The Dominican part of the depression is called the Hoya de Enriquillo. The plain is bounded on the north by the Montagnes du Trou d'Eau and on the south by the Massif de la Selle. It contains the largest inland body of water in the Republic, the Étang Saumâtre, which has no outlet.

The Massif de la Selle, which is named from Mont la Selle, the highest peak in the Republic, is the northwestward prolongation of the Sierra de Bahoruco of the Dominican Republic. It extends westward to the gap in the mountains along a line between Jacmel and Grand-Goave and includes a large coastal plain, the Léogane plain.

The Massif de la Hotte embraces the entire southern peninsula west of a line between Jacmel and Grand-Goave, where it merges into the Massif de la Selle. This region includes a large coastal plain, the Cayes Plain, and several interior lowlands, the largest of which is the Asile Valley. The remainder of the region consists of rugged mountains. The Massif de la Selle and the Massif de la Hotte form an arc convex northward.

Gonave Island is the largest outlying island belonging to the Republic. The southeastern half of the island is more rugged and has a greater variety of surface features than the northwestern half.

DRAINAGE.

General Features.

The Republic of Haiti has a great many small streams. Most of them have short courses, and many of them flow directly down steep mountain

sides. All streams that contain water during most of the year in any part of their courses are called rivières, but this term does not have the significance of size commonly attached to it in other countries. Considerably more than 100 such streams enter the sea along the coast of the Republic. Not more than a third of these, however, are large streams,[1] and of these Rivière Artibonite is the largest.

Most of the streams are swift, shallow, and full of rapids, especially in the mountains, and the water is usually clear except during or immediately after rains. Rivière Artibonite, however, contains no rapids in its lower course, possibly as far up as La Chapelle, and near the sea it becomes rather sluggish. In this region it is also somewhat turbid all the time. Rivière de l'Estère is tidal for several kilometers above its mouth, and a few other streams are tidal for as much as a kilometer or a little more. In colonial days large barges were towed up Rivière Artibonite as far as Petite-Rivière de l'Artibonite. The other streams are navigable only for canoes or very small boats and generally not more than a few kilometers above their mouths.

Drainage Slopes and Principal Streams.

The streams of the Republic may be placed in four groups according to their outlet and general direction of flow. The groups and their principal members are as follows:

1. Streams flowing into the Atlantic Ocean: Rivière Massacre, Grande Rivière du Nord, Rivière du Limbé, Les Trois Rivières, Rivière de Jean Rabel.

2. Streams flowing westward into the Gonaïves Gulf: Rivière de l'Estère, Rivière Artibonite, Grande Rivière du Cul-de-Sac.

3. Streams flowing northward into the Gonaïves Gulf: Grande Rivière de Léogane or Rivière Momance, Grande Rivière de Nippes, Rivière des Baradères, Grande Rivière de Jérémie or Rivière de la Grande Anse.

4. Streams flowing southward into the Caribbean Sea: Rivière de l'Acul, La Ravine du Sud, and Rivière de l'Ilet on the Cayes Plain, Rivière de Cavaillon, Grande Rivière de Jacmel, Rivière de Fesle, and Rivière Pédernales.

The following list gives the approximate lengths of the principal streams, all minor sinuosities being omitted. No tributaries of Rivière Artibonite except Rivière Guayamouc are included. The figures are based on measurements made on two or three maps and data published by Tippenhauer and others. Though admittedly inaccurate the relative order of lengths is probably correct.

[1] Dantès Fortunat, in his Nouvelle Géographie de l'île d'Haïti, pp. 249-250, Paris, 1888, gives a list of forty-three principal rivers of the Republic, of which eight are tributaries of Rivière Artibonite.

Approximate length of principal streams.

	Kilometers.
Artibonite to headwaters in Dominican Republic[1]	236
Artibonite to farthest headwaters on Rivière Ténèbres near Carice[1]	262
Guayamouc, from Bouyaha to headwaters of Rivière Dorée near Marmelade	108
Les Trois Rivières	96
Grande Rivière du Nord	82
Estère	72
Grande Rivière des Nippes and Rivière Serpent	60
Grande Rivière de Léogane or Momance	56
Rivière Massacre	55
Grande Rivière de Jérémie	50
Grande Rivière du Cul-de-Sac	45

Rivière Artibonite is by far the largest of these streams and has the only extensive and complex drainage system. In the Republic of Haiti it drains an area of about 7,800 square kilometers, approximately three-tenths of the whole country, and in addition about 1,800 square kilometers of Dominican territory.[2] Its principal tributary, Rivière Guayamouc, drains about 2,675 square kilometers, all in the Republic of Haiti, and is probably the country's second largest stream.

Les Trois Rivières undoubtedly is next in order of size, but the others can not easily be placed without more accurate maps and streamflow data. Grande Rivière de Nippes, Rivière de Cavaillon, Grand Rivière de Jérémie, Grand Rivière du Nord, and Grand Rivière de Léogane are the largest streams except the tributaries of the Artibonite.

Peculiar Drainage Features.

Certain areas have peculiar drainage, due to geologic or climatic conditions. Underground drainage in limestone is one of the commonest of these peculiar features. In areas of underground drainage the surface water disappears into sink holes or caves in limestone and there are no surface streams. The best example of such an area is on the northern slope of the southern peninsula from Baradères to Jérémie. This region is full of sink holes that have no outlets and contains few surface streams. Some of the surface streams disappear into limestone caverns; others, such as Rivière Salée, west of Baradères, appear suddenly from caverns. Areas of sink-hole drainage are common in regions where limestone is the surface rock, but most of them are not very large. Lost streams of the desert type, which disappear by evaporation or by infiltration into alluvium, are rather common in some areas. Usually they originate on moun-

[1] Tippenhauer and others have given the length of the Artibonite as 320 kilometers. This length must include many minor sinuosities, which in the lower course are very numerous.

[2] Areas measured by planimeter on Thomasset map. Although the map is not very accurate, the errors probably very nearly compensate one another.

tain slopes, where rainfall is abundant, and disappear at or near the arid lowlands. Rivière du Môle, at Môle St.-Nicolas, which disappears 2 kilometers from the sea, is a good example. Other examples are Rivière Blanche, which disappears on the Cul-de-Sac Plain, and, to some extent at least, Grande Rivière du Cul-de-Sac. These streams flow through to the sea, however, in time of flood. Some streams of this type are interrupted streams. They flow perennially in certain stretches where the structure of the rock brings the water to the surface and disappear in other stretches where the gravel fill is deep. Rivière Colombier at Terre-Neuve is a good example.

Lakes.

The Republic of Haiti contains a considerable number of small lakes, most of which occupy sink holes in limestone. Some of them are permanent; others are ephemeral. There are also a few small lakes of the desert-playa type, particularly on the Arbre Plain. Perhaps the Étang Bois-Neuf, south of St.-Marc, also is of this type. There are two rather large lakes, the Étang Saumâtre, at the eastern end of the Cul-de-Sac Plain, and the Étang de Miragoâne. The area of the Etang Saumâtre is about 180 square kilometers and that of the Étang de Miragoâne perhaps 25 square kilometers.[1] The Étang de Miragoâne overflows to the sea, but the Etang Saumâtre has no outlet. West of Étang Saumâtre is a shallow lake called Trou Caïman, which occasionally overflows to the sea.

Drainage of Gonave and Tortue Islands.

Gonave and Tortue islands are characterized generally by underground drainage in limestone. A few subterranean streams break out as springs and flow for short distances, but no perennial surface streams reach the sea.

Relation of Drainage to Structure.

The adjustment of the drainage to the structure of the rocks is discussed in Part III separately for each of the geographic provinces.

Rivière Artibonite and Les Trois Rivières are the only streams that traverse more than one geographic province, except many smaller streams that rise in mountains and flow into the larger plains. The Guayamouc and Artibonite drainage is closely adjusted to the structure in its upper and lower parts, but the middle part, between Las Cahobas and Mirebalais, is unrelated to the structure. Rivière Guayamouc flows southeastward in a plunging synclinal trough, and Rivière Artibonite below Mirebalais flows northwestward in a similar trough. The diversion of Rivière Artibonite across the Montagnes Noires is discussed on pages 381-382. Les Trois Rivières flows along the strike of the rocks from its headwaters

[1] Areas measured by planimeter from Thomasset map. The measurement gives 29 square kilometers for Étang de Miragoâne, but this probably is too great.

to Pilate and then cuts obliquely across the strike. At Gros-Morne it enters a downfaulted trough and follows this trough northward to the sea.

Detailed descriptions of the drainage with regard to water supply and power development are given on pages 513-595.

CLIMATE.

Source of Data.

Nearly all the data regarding climate are taken from the bulletins of the Observatoire Météorologique du Séminaire-Collège St. Martial,[1] which have been published semiannually for the period from July, 1909, to the end of 1916, and annually since that time. The data contained in the bulletins were collected under the supervision of J. Scherer, Directeur de l'Observatoire. Records of rainfall and temperature at many stations extend back a few years prior to 1909 but are summed up in the Bulletin Semestriel for July to December of that year. Records at Port-au-Prince covering a much longer period of observation also are summarized in different issues of the bulletin. Data from Moreau de Saint-Méry [2] that are definite enough to be of value are used to a small extent to supplement those taken from the bulletins.

Temperature.

All parts of the Republic have a warm and notably equable temperature. Frost, snow, and ice probably do not form anywhere in the Republic,[3] even at the highest altitudes, although the temperatures on the high mountain ranges are appreciably less than those at lower altitudes.

Most of the stations at which temperature observations have been made are at low altitudes on plains, in valleys, or near the sea. The records made represent the conditions under which the greater part of the population of the Republic lives, but they do not give an entirely correct idea of the purely physical aspect of the climate. Only one station, Furcy, is located at a really high altitude, and the records from this station, though incomplete, are sufficient to show a considerably lower temperature than that prevailing on the lowlands. The following tables give the mean monthly temperatures at a number of well-distributed stations over the period for which records are available. The averages of the monthly means for the years of record available also are given.

[1] Imprimerie Nationale, Port-au-Prince. The bulletin for 1919, published in 1920, was the most recent one used in compiling the tables. The bulletins for 1920 and 1921 have been published in the meantime.

[2] Moreau de Saint-Méry, L. E., Description topographique, physique, civile, et politique de la partie française de l'isle Saint-Domingue, 2 vols., Philadelphia, 1797-98.

[3] Moreau de Saint-Méry (vol. 2, p. 505) states that in the Canton of Fond Jean-Noël, northwest of Sal-Trou, near the crest of Montagne de la Selle, "one experiences a sensation of coldness and sometimes one even sees a kind of frost." His statement is so qualified as to be rather doubtful, considering the lack of confirmatory evidence.

Monthly mean temperature at places in Haiti.

[Degrees Centigrade.][a]

Cap-Haïtien; altitude, 15 meters.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1909 ..	....	....	....	....	....	....	27.1	....	....	25.0	22.5	21.5
1910 ..	20.7	21.8	21.9	23.3	24.7	25.8	25.9	26.3	25.2	25.8	24.2	22.5
1911 ..	22.6	22.4	22.7	24.6	25.1	27.0	27.6	27.7	27.8	26.4	26.9	24.2
1912 ..	24.8	24.6	25.5	25.8	26.4	27.3	27.2	27.5	27.9	27.1	25.8	24.9
1913 ..	23.8	23.8	24.9	23.9	24.4	25.8	26.0	....	....	....	25.1	24.4
1914 ..	23.2	23.6	23.4	25.2	26.1	26.5	26.8	26.5	27.0	26.5	24.8	24.3
1915 ..	23.7	21.5	22.5	22.8	....	....	....	....	....	....	....	....
1916 ..	....	....	....	....	....	....	....	....	....	....	....	....
Mean .	23.1	22.9	23.5	24.3	25.3	26.5	26.8	27.0	27.0	26.2	24.9	23.9

[a] All means are obtained by adding the maximum and minimum and dividing by two.

Bayeux; altitude, 10 meters.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1909 ..	....	....	....	....	....	....	27.6	27.1	26.8	25.0	24.0	22.1
1910 ..	21.6	22.2	22.4	23.8	25.2	26.3	26.8	26.8	26.3	25.8	24.8	25.2
1911 ..	22.5	22.6	22.6	24.2	25.1	26.3	26.8	....	27.0	26.3	25.8	23.9
1912 ..	....	....	....	....	....	....	....	....	....	....	....	....
1913 ..	23.0	25.6	23.9	23.0	24.1	25.4	26.1	26.3	26.0	25.4	24.2	23.4
1914 ..	23.0	23.2	23.1	25.0	25.9	26.3	....	....	....	....	....	....
1915 ..	....	....	....	....	....	....	27.4	27.4	27.1	26.9	24.9	23.6
1916 ..	22.4	22.3	22.3	25.1	25.4	26.8	26.5	27.0	26.6	25.7	24.5	22.5
Mean .	22.5	23.2	22.9	24.2	25.1	26.2	26.9	26.9	26.6	25.8	24.7	22.4

Port-de-Paix; altitude 25 meters.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1909 ..	....	....	....	....	....	....	26.8	26.2	26.0	26.4	24.5	22.7
1910 ..	20.9	21.8	22.7	23.9	25.1	26.6	26.2	26.3	26.6	26.1	....	23.7
1911 ..	21.6	22.3	22.2	24.3	24.9	26.5	26.9	27.3	27.2	....	....	....
1912 ..	....	....	....	....	....	....	....	....	....	....	....	....
1919[a] .	21.6	22.3	21.9	24.2	25.5	26.2	26.8	26.5	26.6	25.7	24.2	22.6
Mean .	21.4	22.1	22.3	24.1	25.2	26.4	26.7	26.6	26.6	26.1	24.3	23.0

[a] Furnished by M. Abbeg, Port-de-Paix.

Monthly mean temperature at places in Haiti—Continued.

Gonaïves; altitude, 3 meters.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1911 ..	....	....	25.5	26.8	26.6	28.2	28.7	28.7	....	28.0	27.4	25.6
1912 ..	25.7	26.0	27.6	27.3	27.6	....	....	....	28.2	27.6	27.4	26.4
1913 ..	26.0	25.4	26.7	25.8	27.1	27.3	27.5	27.2	26.8	26.9	26.2	25.2
1914 ..	24.5	....	26.1	27.3	28.1	28.4	29.3	29.2	28.8	28.1	26.9	26.9
1915 ..	26.6	25.4	26.9	26.8	28.3	28.5	....	....	....	....	....	....
1916 ..	25.7	25.2	25.6	27.2	28.0	....	....	....	28.0	27.3	26.6	24.4
Mean .	25.7	25.4	26.4	26.9	27.6	28.1	28.5	28.4	27.9	27.6	26.6	25.7

Gantier; altitude, 117 meters.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1909 ..	....	....	....	....	....	....	27.2	26.7	26.7	26.5	23.6	22.0
1910 ..	22.9	23.7	23.4	25.1	26.4	27.5	27.2	27.4	26.6	26.5	26.4	23.9
1911 ..	23.7	24.1	24.6	25.5	26.5	26.7	27.8	28.1	27.8	26.9	26.4	24.1
1912 ..	24.4	25.6	26.8	27.0	29.0	28.2	28.8	28.8	27.7	26.1	26.9	26.4
1913 ..	24.4	25.6	26.9	25.8	26.8	27.6	28.1	27.9	27.5	27.4	26.4	25.2
1914 ..	24.0	24.6	25.2	27.4	28.2	28.0	28.0	28.6	28.2	27.8	25.9	25.9
1915 ..	24.6	25.2	25.5	26.2	27.1	27.9	28.5	28.5	28.6	28.6	27.0	25.7
1916 ..	....	....	....	26.9	27.1	27.5	27.6	27.5	27.3	26.9	25.4	23.8
Mean .	24.0	24.8	25.4	26.3	27.3	27.6	27.9	27.9	27.5	27.1	26.0	24.6

Port-au-Prince; altitude, 37 meters.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1909 ..	....	....	....	....	....	....	28.9	28.0	27.2	27.3	24.8	23.7
1910 ..	24.5	25.2	24.7	26.0	26.6	28.0	28.3	28.2	27.5	26.6	26.1	25.5
1911 ..	25.4	25.3	25.5	26.9	26.3	28.4	29.2	28.7	28.2	26.6	26.4	26.0
1912 ..	26.1	26.1	26.9	26.7	27.5	28.4	28.8	28.2	27.5	26.9	27.1	26.4
1913 ..	26.2	26.3	27.1	25.6	26.1	27.9	28.2	28.3	27.4	26.8	26.0	25.4
1914 ..	25.2	25.9	26.4	26.4	27.8	28.1	29.6	28.9	28.4	27.6	26.1	26.2
1915 ..	26.5	26.0	27.0	26.2	28.2	28.8	29.2	28.8	28.2	28.1	27.2	26.6
1916 ..	26.3	26.1	26.5	27.2	27.6	27.9	27.7	28.6	27.9	26.8	26.0	24.7
Mean .	25.7	25.8	26.3	26.4	27.2	28.2	28.8	28.5	27.8	27.1	26.2	25.6

Monthly mean temperature at places in Haiti—Continued.

Pétionville; altitude, 400 meters.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1909 ..	....	....	....	....	....	....	27.0	26.1	25.5	25.4	22.4	21.6
1910 ..	21.6	22.5	22.8	24.0	24.6	25.6	26.0	26.3	26.6	24.8	24.1	22.7
1911 ..	22.3	23.2	23.8	24.7	24.3	25.8	26.6	26.6	25.8	24.9	24.2	23.0
1912 ..	23.8	23.9	24.3	24.6	25.4	24.8	26.3	26.2	26.0	25.1	24.6	23.7
1913 ..	....	....	....	....	....	....	26.0	26.1	25.0	24.2	23.8	22.6
1914 ..	22.5	23.3	23.9	25.2	25.7	25.7	27.3	26.9	26.6	25.9	25.1	24.3
1915 ..	24.2	23.3	25.1	24.0	26.1	26.4	27.2	26.7	26.3	26.2	25.3	24.9
1916 ..	24.3	24.0	24.0	24.8	25.5	25.8	25.6	25.9	25.9	24.0	23.5	22.4
Mean .	23.1	23.4	24.0	24.5	25.3	25.7	26.5	26.3	26.0	25.1	24.1	23.1

Les Cayes; altitude, 7 meters.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1909 ..	....	....	....	....	....	....	27.4	26.7	25.5	26.0	25.5	24.3
1910 ..	24.0	23.8	23.7	24.4	25.4	26.7	26.7	26.9	26.8	26.3	26.2	25.0
1911 ..	24.3	24.0	....	....	....	....	....	27.9	28.2	27.2	26.6	25.9
1912 ..	26.0	25.2	25.7	25.5	26.5	....	....	....	27.1	27.1	26.8	25.8
1913 ..	24.6	24.5	25.4	24.8	25.8	26.8	26.3	26.7	26.6	26.5	26.1	25.0
1914 ..	24.3	24.7	25.0	25.7	26.7	27.5	27.2	27.1	27.0	26.9	26.0	25.9
1915 ..	24.8	24.8	25.5	25.6	26.5	27.3	26.9	27.0	26.9	27.1	26.7	25.8
1916 ..	24.8	24.7	24.6	25.3	26.4	26.8	26.9	26.7	26.7	25.7	25.6	25.1
Mean .	24.7	24.7	25.0	25.2	26.2	27.0	26.9	27.0	26.8	26.6	26.2	25.3

Furcy; altitude, 1,540 meters.

Year.	Aug.	Days of record.	Sept.	Days of record.	Dec.-Jan.	Days of record.
1906....	19.9	.....	20.3	1-12	....	.....
1907....	19.6	.....	19.5	1-15	17.9	Dec. 1-31.
1908....	19.7	.....	19.3	1-16	....	.....
1909....	19.0	.....	18.9	1-15	....	.....
1910....	19.2	.....	19.3	1-16	....	.....
1911....	19.7	.....	19.8	1-14	....	.....
1912....	19.2	3-31.....	19.0	1-18	17.4	Dec. 24-Jan. 4.
1913....	18.4	.....	18.8	1-17	17.5	Dec. 24-Jan. 4.
1914....	19.4	.....	19.6	1-14	17.3	Dec. 23-Jan. 3.
1915....	19.6	1-11, 17-31.....	19.6	1-16	18.0	Dec. 28-Jan. 7.
1916....	19.7	1-13, 16-29, 31.....	19.3	1-13	....	.....
1917....	18.6	.....	18.3	1-15	....	.....
Mean...	19.3	.....	19.3	....	17.5	.....

A notable feature of all these records is the small difference, generally about 5° C., between the highest and lowest monthly mean temperature At Furcy this relation is even more striking, as there appears to be a difference of less than 2° C. between the mean winter and the mean summer temperature. The annual means of the different stations, arranged according to increasing temperature, are as follows:

	°C.
Furcy (approx.)	18.4
Port-de-Paix	24.6
Bayeux and Pétionville	24.8
Cap-Haïtien	25.1
Les Cayes	26.0
Gantier	26.4
Port-au-Prince	27.0
Gonaïves	27.1

The yearly temperature ranges and the comparisons of different stations are shown in Figure 2, which gives the curves of the average monthly means at seven stations. The curves show that Port-de-Paix has a winter temperature well below that of any other station at which records have been kept, but its summer temperature is higher than that of Pétionville and very nearly the same as that of Cap-Haïtien and Bayeux. The curve for Bayeux is omitted because it interferes so much with the curves for Cap-Haïtien and Port-de Paix. Les Cayes has a high winter and low summer temperature, its yearly range being only 2.3° C. Port-au-Prince and Gonaïves are quite the hottest places for which records are available. Although Port-au-Prince has a slightly higher monthly mean in midsummer, its yearly average is 0.1° C. less than that of Gonaïves, which is therefore the warmest city in the Republic. An interesting comparison is afforded by the curves for Port-au-Prince and Pétionville. The two curves are nearly identical in shape, but the temperature of Port-au-Prince averages 2.2° C. higher than that of Pétionville. The stations are only about 7 kilometers apart, but Pétionville is 400 meters above sea level, as compared with 37 meters for the post of observation at Port-au-Prince. Largely because of its cooler climate Pétionville has acquired much popularity as a residential suburb of Port-au-Prince. The records for Port-au-Prince, Pétionville, and Furcy indicate an average lowering of the annual mean temperature of about 1° C. for each 150 meters increase in altitude above sea level.

In reading Figure 2 allowance should be made for the great exaggeration in the vertical scale necessary to bring out the yearly variation of temperatures and the differences between stations. As has been stated, the actual difference between winter and summer temperatures is small.

The daily variation of temperature at most of the stations is about 10° C. or a little less. At Port-au-Prince it averages 10.6° C., as shown by records extending from 1888 to 1910, inclusive. At Furcy it appears

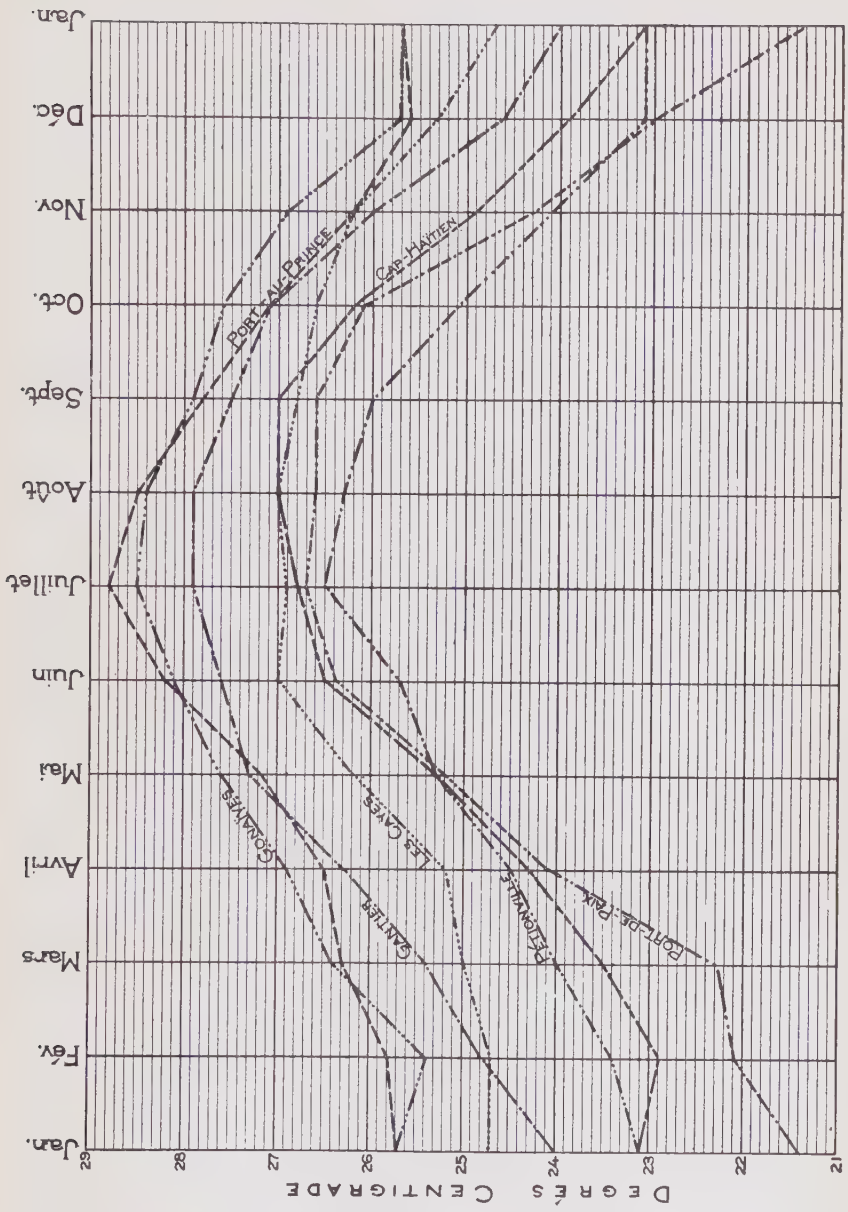


FIGURE 2.—Curves showing monthly mean temperature for different stations.

to be about 9° C. The mean daily difference in degrees Centigrade between maximum and minimum temperatures at Port-au-Prince by months based on readings taken hourly from 1888 to 1910 is as follows: January, 10.7; February, 11.3; March, 11.1; April, 10.6; May, 9.8; June, 10.5; July, 11.4; August, 11.3; September, 10.3; October, 9.6; November, 9.5; December, 10.1.

The variations appear to have some relation to rainfall, as they are smallest in the months of May, October, and November. May and October have heavy precipitation, but November has only an average amount. The variations are greatest in February, July, and August. July is the driest summer month and February is a dry winter month.

At Port-au-Prince the minimum daily temperature, based on monthly observations over a period of 16 years, occurs at 6 a. m. from November to March, inclusive, and at 5 a. m. from April to October. The daily maximum occurs at 1 p. m. from November to April, inclusive, and occurs sometimes at 12 and sometimes at 1 p. m. during the rest of the year.

For 1909 to 1916, inclusive, the maximum temperature recorded at Port-au-Prince was 37.8° C., on August 2, 1914. The minimum at Port-au-Prince was 15.2° C., on February 4, 1910. A minimum of 12.2° was recorded at Pétionville on February 3, 1910, evidently an effect of the same cold wave. The lowest recorded temperature elsewhere, except at Furcy, is 13° C. at Port-de-Paix on February 20, 1911, and March 9, 1911. At Furcy the maximum temperature recorded in the incomplete records available is 27.2° C. on September 6, 1906, and the minimum is 10.8° C. on January 2, 1913. Moreau de Saint-Méry states that in colonial days maximum temperatures of 40° C. (converted from Réaumur scale) were recorded at Le Trou, Port-au-Prince, and on the Plaine du Port-à-Piment (called Arbre Plain in this report) and that minimum temperatures of 5° C. in the parish of Dondon and 7° C. in the Canton of Nouvelle-Touraine (near Furcy) had been observed. These figures probably give a fair idea of the range of maximum and minimum temperatures throughout the Republic.

In the lowlands the high temperatures of summer are rather oppressive, particularly to persons not acclimated to the tropics, and the directness and intensity of the sun's rays add to the discomfort. It is often dangerous to exercise strenuously in the midday heat. Fortunately the nights generally are cool enough to permit refreshing sleep, although this is by no means always true in summer. At altitudes of 900 meters or more above sea level the winter nights seem chilly to persons accustomed to the lowlands, and at altitudes of 1,500 meters or more even the permanent inhabitants at times suffer considerably from cold. Some extra clothing is necessary for travelers in the mountains, and a camp fire is occasionally very pleasant. A sudden drop of several degrees in temperature often accompanies storms and causes unpleasant coldness even in the lowland plains.

Precipitation.

The precipitation in the Republic, which comes chiefly as rain, is notably lacking in the uniformity and equability that characterize the temperature. The amount of precipitation varies greatly both with the seasons and at different localities. For the local irregularities the surface features are mainly responsible. The country is exceedingly mountainous, and the high ranges cause condensation of the moisture carried by the winds so that the rainfall is great on the windward side and very small on the leeward side, only a short distance away. Within the Republic there are all gradations in climate from very humid to semiarid and even to arid, and these gradations are characteristic not of large and homogeneous regions but of small and scattered districts. The effect of differences in the annual precipitation is most apparent on the vegetation and the agricultural development at different localities. In some places, such as the Arbre Plain, the vegetation is all of arid types, particularly cacti, and agriculture is almost impossible without irrigation. In other places, such as the valley of Dondon, there is a luxuriant natural forest, and crops flourish without irrigation. Many mountain ranges, such as the Montagnes la Hotte, are well watered and heavily forested.

One feature of the rainfall, however, is very constant over all the Republic, and that is its concentration into two well-defined wet or rainy seasons, one in the spring, the other in the fall. The following tables of rainfall by months at the most important observation stations not only show this feature of the rainfall but give in some detail the available rainfall records for a considerable number of years at stations where observations have been made over a sufficient interval of time to be of considerable value for use as engineering data. The writer has found it impossible to make some monthly means based on Scherer's yearly records agree with the means published by him. Some of the discrepancies are due to his use of data that had not appeared in the yearly records; others appear to be due to typographical errors in the bulletins. Most of the discrepancies are not large enough to be of much significance.

The second table, which contains the stations arranged in alphabetical order, gives only monthly means of rainfall and the number of years of observation at all stations where any records whatever have been kept for more than a year. This table gives a rough indication of the probable rainfall at a considerable number of stations that were maintained for only a short time and places the data for other stations in alphabetical order for more ready reference.

A final table gives the total yearly rainfall at all stations where the records cover sufficient time to make the means of real value, usually at least seven years. An appendix to this table gives records of annual rainfall in colonial days at a number of places, as published by Moreau de Saint-Méry. These records, although probably not so reliable as those

published by the Observatoire Météorologique, are valuable because they give an indication of the approximate amount of rainfall at some important places for which no recent records are available and because they indicate that the climate has not, as is sometimes suggested, changed radically in historical times. The long record at Léogane gives a result not much different from that of the recent observations. That at Le Trou corresponds closely with Cap-Haïtien and Limonade, as would be expected.

Rainfall in millimeters by months.

Cap-Haïtien.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1906-1909[a]	128.9	84.9	56.0	27.3	133.7	129.5	45.1	46.2	68.3	216.7	187.7	132.2
1909 ..	....	....	....	....	....	....	20.7	209.5	295.2	293.8	753.0	159.5
1910 ..	324.3	40.4	459.6	13.3	7.0	55.9	39.2	46.9	98.6	293.0	146.3	921.6
1911 ..	76.8	88.8	15.6	32.0	224.3	8.4	13.8	31.7	97.6	419.9	67.1	678.8
1912 ..	183.6	90.1	5.6	86.4	94.5	9.2	17.7	21.4	23.3	370.3	526.6	14.1
1913 ..	3.9	1.6	38.3	304.8	191.9	10.9	0.6	42.2	80.2	98.7	223.6	157.7
1914 ..	133.9	100.6	152.8	46.3	82.2	64.6	17.5	0.0	46.0	301.5	367.4	102.4
1915 ..	111.9	426.8	237.1	140.9	....	....	15.3	13.0	144.1	220.1	373.6	133.5
1916 ..	112.3	244.0	42.5	2.0	143.7	24.4	121.5	23.7	87.5	145.6	....	1.0
1917 ..	10.0	70.0	11.0	149.5	197.0	186.1	0.0	14.0	67.0	127.0	278.4	378.0
1918 ..	....	....	....	....	....	....	117.0	....	58.0	169.0	....	55.0
1919 ..	152.5	72.6	....	117.3	278.9	....	....	....	....	....	....	....
Mean .	123.5	109.7	98.9	77.1	145.4	79.8	38.4	45.1	92.5	237.6	299.9	230.6

[a] Figures for January to June in this line show mean rainfall, 1906-1909; figures for July to December show mean rainfall, 1906-1908.

Port-de-Paix.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1907-1909[a]	112.4	115.1	36.9	21.8	64.9	83.9	47.0	109.2	244.5	100.8	129.5	181.5
1909 ..	....	....	....	....	....	....	161.0	186.5	261.0	311.4	638.0	39.0
1910 ..	582.1	67.0	103.0	32.5	58.0	114.0	66.0	185.0	173.0	297.5	....	540.0
1911 ..	133.3	35.0	18.5	103.5	151.0	65.0	34.0	57.0	111.0	....	....	372.5
1912 ..	....	124.0	16.0	52.0	35.3	52.0	40.5	102.5	99.0	258.0	666.0	105.0
1913 ..	175.0	27.0	18.0	247.0	86.5	27.0	39.0	66.0	75.0	79.0	182.0	45.0
1914 ..	106.0	67.0	113.0	38.0	30.0	59.0	14.0	15.5	76.5	13.0	111.0	12.0
1915 ..	50.0	104.2	45.0	83.0	46.0	102.5	91.5	84.0	269.0	46.0	130.0	64.0
1916 ..	150.4	95.0	39.5	36.0	69.0	120.7	36.5	106.5	48.5	129.5	287.0	23.0
1917 ..	80.0	110.5	28.0	95.5	107.5	278.0	57.0	131.0	112.0	47.0	180.5	106.5
1918 ..	19.5	70.0	29.5	87.5	42.5	74.0	13.0	59.0	79.5	75.5	113.0	97.0
1919 ..	90.5	33.0	42.5	81.0	114.0	37.5	6.0	30.0	112.0	93.0	15.0	62.0
Mean .	143.6	82.9	43.3	71.5	71.9	90.9	50.2	95.5	146.6	129.3	234.7	140.7

[a] Figures for January to June in this line show mean rainfall, 1907-1909; figures for July to December show mean rainfall, 1907-1908.

Rainfall in millimeters by months—Continued.

Môle St.-Nicolas.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1905-1909[a]	49.9	27.0	50.3	3.1	65.9	13.7	33.0	13.7	120.6	100.5	25.8	33.2
1909 ..	....	....	....	....	....	....	23.0	175.3	217.6	128.1	196.7	27.0
1910 ..	125.5	17.2	24.5	21.6	0.0	79.9	48.8	33.0	44.6	89.8	22.4	134.4
1911 ..	33.6	0.0	3.4	0.0	103.6	0.0	0.0	....	5.0	16.5	0.0	6.0
1912 ..	127.1	183.0	....	....	....	....	....	....	....	93.7	110.2	0.0
1913 ..	0.1	102.0	0.0	59.0	26.8	20.0	11.0	6.9	51.8	0.6	157.2	3.2
1914 ..	91.2	32.1	32.7	93.0	86.2	36.3	41.6	....	....	....	....	....
1915 ..	17.7	77.2	29.5	23.9	44.4	53.3	24.2	41.3	29.5	14.8	13.6	0.4
1916 ..	0.0	8.2	14.3	13.5	23.8	38.4	19.6	88.9	14.6	8.76	123.0	0.0
1917 ..	1.9	11.1	0.0	105.9	49.6	24.9	16.9	68.7	40.7	29.7	169.8	85.4
1918 ..	....	11.3	3.3	32.5	23.5	17.0	22.7	0.0	51.4	252.2	5.5	13.3
1919 ..	4.8	0.0	1.9	0.0	149.0	8.4	24.7	1.7	5.2	2.2	46.1	58.4
Mean .	46.5	32.4	25.8	26.1	59.7	24.8	26.0	39.2	72.5	79.8	67.7	32.9

[a] Figures for January to June in this line show mean rainfall, 1905-1909; figures for July to December show mean rainfall, 1905-1908.

Gonaïves.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1903-1909[a]	7.3	5.7	9.7	24.4	84.9	88.3	81.7	35.9	101.2	54.9	19.9	5.6
1909 ..	....	....	....	....	....	....	91.0	202.5	....	....	....	....
1910 ..	28.0	0.0	50.0	5.0	39.2	182.8	96.5	77.9	64.4	119.4	0.0	66.9
1911 ..	0.0	0.0	0.0	21.7	141.2	101.7	33.8	55.3	52.7	32.4	24.0	76.4
1912 ..	6.0	60.4	44.5	4.1	64.7	83.5	109.4	68.4	31.2	69.3	11.5	0.0
1913 ..	0.0	1.8	13.7	50.1	22.5	92.3	23.2	66.7	130.5	21.4	10.7	0.0
1914 ..	18.3	14.8	54.7	72.3	41.0	52.5	30.8	55.0	62.8	4.5	142.2	6.1
1915 ..	18.0	23.3	8.8	10.6	7.1	146.1	....	....	....	....	....	18.0
1916 ..	0.0	30.3	0.0	12.2	115.1	148.6	50.0	38.0	175.6	67.0	46.4	0.0
1917 ..	0.0	0.0	3.8	56.0	107.6	132.6	37.6	42.5	17.4	8.5	1.1	4.3
1918 ..	0.0	27.0	3.7	8.0	70.9	71.1	56.6	7.6	163.6	45.5	0.0	0.0
1919 ..	2.1	0.0	22.4	0.0	95.8	86.5	55.9	0.0	95.2	0.0	0.0	2.5
Mean .	7.3	11.6	15.8	24.2	76.4	100.9	63.2	58.1	93.8	47.0	23.4	12.7

[a] Figures for January to June and September to December in this line show mean rainfall, 1903-1909; figures for July and August show mean rainfall, 1903-1908.

St.-Marc.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1905-1909[a]	7.9	20.4	18.6	60.7	180.4	145.2	124.8	134.8	176.5	149.6	21.3	2.5
1909 ..	....	....	....	....	....	....	145.7	165.7	189.0	91.7	89.6	0.0
1910 ..	54.0	50.2	0.0	0.0	36.2	177.1	119.9	18.5	76.9	108.9	0.0	23.2
1911 ..	0.0	0.0	0.0	28.3	180.9	128.2	96.4	173.3	143.6	72.1	38.6	33.1
1912 ..	5.5	21.0	18.0	11.3	45.2	180.8	179.0	....	....	....	....	....
1919 ..	0.0	0.0	7.3	3.4	131.9	82.5	157.8	69.9	68.2	92.2	12.7	21.9
Mean .	11.0	19.3	13.1	38.5	144.0	143.8	133.1	120.8	148.0	120.4	28.3	11.0

[a] Figures for January to June in this line show mean rainfall, 1905-1909; figures for July to December show mean rainfall, 1905-1908.

Rainfall in millimeters by months—Continued.

St.-Michel de l'Atalaye.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1908-1909[a]	21.6	13.5	46.3	68.7	186.8	208.6	212.0	46.7	233.4	131.1	101.1	46.0
1910 ..	30.0	0.0	26.6	72.9	65.9	109.9	73.2	176.0	125.0	100.0	75.4	126.0
1911 ..	17.3	0.0	7.0	58.0	388.0	176.3	49.0	158.0	98.0	107.6	17.0	65.0
1912 ..	0.0	12.4	78.0	30.0	119.0	182.0	68.9	143.2	179.4	196.0	48.0	0.6
1913 ..	0.0	0.0	56.0	59.0	114.0	121.0	....	....	160.0	110.0	25.0	8.0
1914 ..	18.6	7.0	41.0	169.0	62.0	20.0	....	....	118.5	142.4	72.4	29.0
1915 ..	2.2	21.3	4.3	23.9	227.1	592.2	210.0	60.1	26.6	70.6	12.0	0.0
1916 ..	0.0	6.0	16.0	33.0	163.5	327.6	....	....	180.2	131.8	140.2	0.0
1917 ..	0.0	2.6	0.0	131.1	176.4	139.1	48.0	....	105.7	162.7	90.7	45.0
1918 ..	5.0	2.0	68.0	103.0	115.4	120.0	208.8	127.2	109.1	127.7	12.0	13.3
1919 ..	15.1	0.0	21.0	62.2	272.1	175.6	104.4	....	137.2	55.0	24.5	8.6
Mean .	10.9	6.5	34.2	73.3	171.4	198.4	119.1	163.7	143.6	118.5	75.3	32.3

[a] Figures for January to June in this line show mean rainfall, 1908-1909; figures for July to December show rainfall, 1908.

Mirebalais.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1907-1909[a]	3.7	47.2	83.9	169.3	277.4	189.4	222.7	220.7	298.2	169.9	35.0	6.0
1909 ..	....	....	....	....	....	....	121.5	....	....	248.2	173.0	42.0
1910 ..	20.0	0.0	85.0	32.0	293.7	325.0	169.0	396.4	348.2	150.0	79.0	207.0
1911 ..	43.5	2.0	34.5	105.5	242.5	192.5	399.9	403.3	281.0	163.0	118.0	24.0
1912 ..	8.0	16.0	119.0	212.0	304.0	243.0	351.0	289.0	343.0	264.0	118.0	6.0
1913 ..	35.0	25.0	81.0	203.0	277.0	199.0	291.0	635.0	525.0	156.0	17.0	119.0
1914 ..	20.0	38.0	125.0	86.0	472.0	426.0	201.0	388.0	554.0	673.0	405.0	144.0
1915 ..	0.0	2.0	0.0	182.0	509.0	527.0	596.0	456.0	434.0	446.0	100.0	95.0
1916 ..	36.0	287.0	151.0	333.0	746.0	791.0	436.0	385.0	597.0	789.0	492.0	1.7
Mean .	17.4	51.2	84.7	166.1	367.6	327.2	301.0	361.5	397.7	322.9	157.2	65.1

[a] Figures for January to June and August and September in this line show mean rainfall, 1907-1909; figures for July and October to December show mean rainfall, 1907-1908.

Thomazeau.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1905-1909[a]	16.8	31.9	41.6	107.5	154.8	32.4	42.5	82.5	150.1	150.6	42.7	8.7
1909 ..	....	....	....	....	....	....	10.0	105.0	119.4	87.6	199.1	0.0
1910 ..	6.0	0.0	37.6	87.6	58.5	85.8	88.8	70.1	161.5	62.5	71.0	63.0
1911 ..	0.0	14.5	27.3	78.9	124.0	21.0	27.0	3.0	92.0	136.8	128.0	0.0
1912 ..	0.0	39.1	62.8	114.1	133.5	50.0	83.3	124.0	160.7	109.0	4.0	0.0
1913 ..	0.0	0.0	0.0	96.3	105.8	7.0	96.0	45.0	69.2	155.1	33.3	17.0
1914 ..	14.8	37.8	5.5	45.0	161.0	120.0	29.0	56.5	66.0	180.0	160.0	20.8
1915 ..	14.0	35.0	10.5	35.7	151.5	234.5	280.8	164.0	109.6	....	....	....
1916 ..	....	....	....	....	....	....	36.4	....	153.6	143.3	150.0	0.0
1917 ..	0.0	17.3	7.0	148.5	198.1	145.1	62.4	44.3	75.5	129.9	78.4	15.6
1918 ..	0.0	17.6	120.2	55.3	281.9	49.7	51.0	58.1	131.0	144.9	99.0	0.0
1919 ..	0.0	0.0	10.2	147.5	21.2	42.2	35.2	32.2	140.9	108.4	0.0	27.5
Mean .	8.5	22.9	34.9	96.2	144.3	65.5	64.7	73.7	125.3	132.8	81.0	12.8

[a] Figures for January to June in this line show mean rainfall, 1905-1909; figures for July to December show mean rainfall, 1905-1908.

Rainfall in millimeters by months—Continued.

Port-au-Prince.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec
1863 ..	....	....	....	....	....	....	....	83.0	128.0	257.0	92.0	18.0
1864 ..	1.0	124.0	111.0	212.0	261.0	59.0	109.0	223.0	164.0	171.0	61.0	45.0
1865 ..	20.0	13.0	78.0	193.0	451.0	75.0	103.0	129.0	298.0	151.0	158.0	28.0
1866 ..	57.0	75.0	149.0	362.0	226.0	146.0	150.0	125.0	131.0	110.0	125.0	56.0
1867 ..	51.0	27.0	23.0	199.0	323.0	177.0	54.0	139.0	53.0	127.0	63.0	41.0
1868 ..	1.0	143.0	87.0	102.0	317.0	52.0	43.0	129.0	282.0	118.0	118.0	43.0
1869 ..	27.0	141.0	109.0	123.0	326.0	139.0	97.0	265.0	267.0	151.0	29.0	6.0
1883 ..	12.0	36.0	93.0	108.5	....	....	34.0	113.0	29.0	62.0	38.0	0.0
1884 ..	....	59.5	81.9	88.0	275.5	140.9	27.2	139.6	129.4	111.0	44.8	43.7
1885 ..	42.5	58.0	37.1	23.0	92.0	58.1	57.5	89.3	154.6	127.6	19.7	57.6
1886 ..	161.8	73.3	60.6	185.8	204.7	144.9	72.5	223.5	113.5	51.5	....	....
1887 ..	....	....	....	....	453.8	50.3	77.5	210.4	191.0	173.0	74.1	0.8
1888 ..	5.1	11.6	37.3	100.4	179.6	113.0	43.7	85.1	87.5	127.8	155.1	124.7
1889 ..	12.9	21.2	56.5	222.3	464.6	99.2	32.3	108.9	225.9	203.1	4.2	20.1
1890 ..	48.3	78.4	127.5	83.5	119.4	71.2	86.1	106.0	233.5	119.9	94.7	62.0
1891 ..	27.6	116.3	24.7	169.7	332.0	148.6	26.0	198.3	176.3	151.6	124.0	5.4
1892 ..	34.0	26.0	21.9	171.2	169.1	103.4	106.6	145.7	61.6	161.0	50.9	24.0
1893 ..	80.7	52.4	41.9	111.4	302.7	67.2	146.2	217.5	209.7	181.0	4.5	22.1
1894 ..	5.5	6.6	128.5	220.0	212.8	78.5	1.8	72.9	296.9	146.3	24.6	68.7
1895 ..	3.8	62.9	93.4	136.2	209.3	66.6	121.3	173.5	216.3	107.8	114.1	20.0
1896 ..	46.3	26.1	36.2	145.2	170.6	105.5	44.8	206.8	158.4	196.8	9.7	80.3
1897 ..	0.4	6.2	109.9	160.7	423.7	37.0	35.4	105.8	245.2	72.9	44.7	6.3
1898 ..	15.1	67.2	48.7	82.0	302.3	144.4	97.1	156.3	148.8	112.9	61.6	161.2
1899 ..	59.7	13.7	67.2	238.4	204.2	215.4	88.0	81.4	244.0	370.9	18.6	45.2
1900 ..	59.8	8.0	7.6	191.5	209.1	74.1	36.6	99.2	231.6	79.6	121.9	11.4
1901 ..	45.2	7.6	77.0	90.2	289.0	133.2	81.5	71.3	130.0	262.5	44.5	17.9
1902 ..	20.6	230.9	37.4	222.7	489.6	87.6	3.5	102.2	171.8	228.0	47.4	42.0
1903 ..	7.8	0.0	106.8	169.0	116.0	100.6	72.5	110.9	156.5	140.6	209.6	9.7
1904 ..	44.2	42.4	314.7	254.6	195.8	10.8	61.3	71.1	188.6	253.6	64.7	41.4
1905 ..	72.7	79.3	96.1	69.8	233.3	123.1	43.3	168.8	211.7	309.4	126.5	0.1
1906 ..	44.5	135.1	124.4	153.5	252.9	96.1	48.2	194.5	224.9	287.1	60.3	62.0
1907 ..	13.5	85.9	74.9	92.8	249.0	22.9	43.0	108.0	119.1	137.9	81.7	0.5
1908 ..	8.2	276.2	160.7	119.8	168.5	45.3	63.9	186.8	104.8	165.7	23.6	24.6
1909 ..	83.2	31.8	143.0	249.5	112.9	163.8	82.8	127.0	372.2	103.8	246.9	40.8
1910 ..	24.9	1.9	198.0	246.6	159.7	68.9	55.0	135.3	455.6	115.6	69.8	80.2
1911 ..	1.8	20.3	136.6	166.9	258.8	78.7	74.1	67.1	98.4	353.4	120.4	23.2
1912 ..	1.5	30.5	136.5	267.7	219.0	64.8	85.2	213.3	237.6	161.3	29.0	36.8
1913 ..	20.4	17.5	67.5	281.0	185.2	94.5	71.2	103.4	152.1	142.6	165.8	9.4
1914 ..	76.7	18.2	130.8	130.9	138.1	184.7	83.2	248.4	119.2	131.4	189.4	60.0
1915 ..	39.4	23.9	15.5	71.4	200.7	113.1	104.8	271.5	60.0	199.0	35.8	8.2
1916 ..	12.1	42.9	127.8	187.0	242.7	346.6	90.7	61.9	216.0	300.9	308.1	1.0
1917 ..	1.6	40.2	104.6	188.4	277.2	139.3	120.3	160.1	241.6	182.8	51.7	37.2
1918 ..	5.3	30.9	199.4	132.9	317.8	128.0	11.3	77.3	224.9	280.3	69.7	0.0
1919 ..	24.5	61.9	55.3	99.6	156.3	63.4	95.3	27.4	133.1	65.8	58.3	18.2
Mean .	32.2	57.9	93.8	162.4	249.8	105.5	69.5	139.4	184.7	169.6	85.7	35.0

Jacmel.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov	Dec.
1906-1909[a]	35.4	88.4	90.4	113.3	137.4	136.8	77.7	64.8	167.9	98.8	38.3	9.6
1909 ..	....	....	....	....	....	....	54.9	165.5	152.4	159.5	245.2	7.2
1910 ..	49.4	1.0	215.0	117.7	123.9	67.9	46.9	130.6	115.3	139.5	16.7	59.0
1911 ..	12.2	41.8	134.1	208.6	249.4	8.4	46.4	43.6	96.2	151.6	50.3	7.9
1912 ..	40.7	117.5	19.3	142.3	213.0	43.6	127.4	174.6	40.8	170.1	162.2	16.2
1913 ..	4.4	30.6	15.4	242.5	194.3	31.1	75.0	86.7	64.7	79.0	203.6	45.9
1914 ..	90.3	6.3	53.5	181.4	224.2	34.8	27.5	143.7	102.0	56.5	83.0	17.6
1915 ..	33.6	57.2	19.9	81.6	372.2	59.6	97.4	127.7	91.7	55.6	27.5	112 0
1916 ..	10.3	35.6	99.3	65.6	267.8	137.0	56.3	327.3	117.5	400.5	110.4	0.0
1917 ..	0.0	39.9	57.4	141.2	629.5	155.1	90.6	174.9	110.5	199.9	37.0	43.3
1918 ..	6.5	16.6	134.7	196.8	310.8	120.5	94.6	83.9	72.5	162.1	15.9	39.7
1919 ..	79.5	1.7	141.3	138.8	139.3	162.5	114.2	111.1	118.0	32.4	27.2	51.3
Mean .	33.5	50.1	89.4	140.8	233.9	97.7	76.0	126.0	113.2	135.9	78.1	30.6

[a] January to June = 1906-1909; July to December = 1906-1908.

Rainfall in millimeters by months—Continued.

Les Cayes.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1906-1909[a]	64.4	135.7	86.4	189.8	297.5	211.7	75.1	132.6	238.0	313.1	199.3	60.9
1909 ..	....	....	....	....	....	....	46.6	242.3	602.0	432.6	300.2	15.3
1910 ..	40.3	122.1	94.9	157.3	314.0	64.6	106.2	208.8	233.4	213.6	21.5	83.5
1911 ..	25.0	30.0	65.2	136.8	920.0	81.3	18.5	122.2	279.0	423.8	204.1	117.0
1912 ..	179.1	58.2	132.9	246.0	320.1	67.7	103.2	342.2	92.0	317.8	80.4	65.5
1913 ..	36.5	65.5	212.0	150.0	104.0	27.0	87.5	62.5	156.2	110.9	50.8	50.0
1914 ..	60.0	37.2	25.4	271.5	144.7	61.1	21.7	154.5	206.0	85.2	180.4	13.5
1915 ..	86.0	11.2	12.0	140.0	160.8	106.9	166.0	343.0	257.6	44.2	33.8	59.7
1916 ..	33.7	82.0	72.1	255.0	428.0	225.0	195.0	291.9	71.5	794.0	583.8	30.0
1917 ..	16.5	17.8	55.5	142.5	228.3	76.7	132.2	526.3	458.3	1046.5	315.2	482.4
1918 ..	350.3	162.4	120.0	210.0	464.0	265.5	451.5	276.4	193.0	578.6	223.7	289.2
Mean .	83.5	86.9	87.4	189.9	328.8	140.2	119.4	228.3	251.0	383.6	199.4	106.8

[a] January to June = 1906-1909; July to December = 1906-1908.

Jérémie.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1906-1909[a]	71.1	100.7	70.6	64.5	113.7	....	81.9	67.4	147.1	58.7	69.8	17.3
1909 ..	....	....	....	....	....	....	30.3	257.8	78.6	84.0	214.7	12.0
1910 ..	96.9	1.7	202.1	34.1	96.5	60.5	36.0	117.7	13.8	70.7	161.3	130.0
1911 ..	....	....	....	....	....	....	91.1	15.0	53.1	48.8	103.8	172.7
1912 ..	253.4	207.5	26.3	76.6	202.6	69.4	89.6	54.6	219.2	144.2	103.8	181.2
1913 ..	22.3	1.0	94.7	160.1	168.6	99.9	105.0	41.3	78.9	143.4	38.8	71.2
1914 ..	81.1	32.7	93.4	180.0	233.5	73.8	90.9	115.5	114.9	134.0	174.6	5.3
1915 ..	75.0	178.1	63.7	73.7	131.2	102.3	45.9	120.6	76.6	37.8	218.0	68.4
1916 ..	6.6	221.0	39.9	176.8	214.9	273.2	45.3	147.7	55.8	253.6	120.9	0.0
1917 ..	50.8	67.4	43.4	126.5	213.7	319.1	....	....	256.8	....	....	....
1918 ..	44.7	140.7	44.4	178.1	96.1	125.1	126.2	95.9	108.9	232.4	153.3	13.4
1919 ..	312.8	75.0	30.7	152.8	355.9	48.9	239.8	198.6	....	....	....	....
Mean .	93.7	102.1	70.8	109.0	166.8	130.2	88.1	105.1	115.2	110.4	124.9	58.8

[a] January to May = 1906-1909; July to December = 1906-1908.

Moron.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1910 ..	....	....	....	....	....	....	....	....	205.9	532.5	193.8	539.5
1911 ..	76.7	75.4	18.6	112.0	537.6	31.1	74.2	76.1	75.9	132.5	68.3	291.3
1912 ..	255.2	78.6	84.9	112.6	233.0	263.4	....	....	....	118.1	132.5	39.3
1913 ..	22.6	0.1	78.2	276.5	313.3	100.0	164.1	176.8	343.7	134.3	369.1	87.4
1914 ..	100.3	20.5	184.4	221.6	231.3	200.4	150.5	180.0	124.8	306.7	366.9	158.5
1915 ..	89.4	183.3	34.0	93.4	123.3	146.3	163.1	260.0	270.0	246.7	205.0	76.0
1916 ..	63.9	42.8	128.7	171.3	169.8	251.5	163.3	210.0	207.3	340.3	191.8	2.7
1917 ..	23.9	41.8	9.6	270.3	470.6	306.5	145.9	184.0	253.0	269.0	441.1	93.8
1918 ..	6.2	54.8	166.3	483.2	324.0	183.6	122.5	163.1	326.5	405.3	255.0	27.0
1919 ..	107.3	24.0	36.7	201.2	320.0	125.8	....	....	....	....	....	....
Mean .	82.8	57.9	82.4	215.8	302.5	178.7	140.5	178.6	225.9	276.2	247.1	146.2

Station.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Years of record.
Abricots (les)	24.2	22.5	58.9	49.8	105.1	47.4	47.9	21.0	59.0	40.0	87.0	55.5	1 and 2
Anse-à-Veau	36.9	50.1	56.4	130.0	161.7	130.2	108.6	113.2	114.8	91.3	60.9	33.9	9-11
Arcahaie (l')	16.8	28.9	34.6	70.1	129.8	64.0	66.6	82.0	109.9	105.3	64.8	21.1	13
Bahon	34.5	14.7	51.9	51.6	144.0	160.4	116.3	141.1	165.5	214.3	109.6	70.0	8 and 9
Bainet	46.7	39.6	96.8	240.6	231.3	110.0	120.3	112.9	167.0	153.5	91.2	35.3	13
Bassin-Bleu	34.9	33.0	18.9	49.4	123.7	128.7	83.3	117.2	118.1	111.3	106.0	61.6	8-10
Bayeux	176.3	117.5	110.6	193.7	206.1	110.4	45.9	94.2	143.8	217.4	401.5	291.8	17 and 18
Borgne (le)	172.2	112.2	81.8	181.2	115.2	99.8	47.9	50.2	91.7	196.9	387.9	185.2	8
Cap-Haïtien	123.5	109.7	98.8	77.1	145.4	79.8	38.5	45.1	92.5	237.7	298.3	230.7	12 and 13
Cayes (les)	83.5	86.9	87.4	189.9	328.8	140.2	119.4	228.3	251.0	383.6	199.4	106.8	13
Chardonnières	19.3	66.4	75.4	119.3	76.1	48.6	49.1	94.4	136.1	173.2	89.3	27.8	9
Dondon	61.7	40.9	64.6	106.7	165.5	116.2	101.5	100.9	134.3	168.1	174.7	139.0	9 and 10
Fond-Verrettes	30.9	38.2	55.2	146.0	206.1	155.1	74.8	135.1	192.6	180.4	137.7	24.4	12
Gantier	16.3	20.5	41.8	123.7	149.4	51.0	33.2	66.7	116.7	145.2	61.2	26.7	21
Gonaïves	7.3	11.6	15.8	24.2	76.4	100.9	63.2	58.1	93.8	47.0	23.4	12.7	17
Grande-Rivière du Nord	86.5	64.5	78.9	92.1	204.6	83.0	67.9	111.0	171.4	178.9	206.4	167.2	8 and 9
Hinche	24.0	3.0	8.0	88.0	177.0	237.7	149.0	75.0	263.3	68.0	47.5	13.5	2 and 3
Jacmel	33.5	50.1	89.4	140.8	233.9	97.7	76.0	126.0	113.2	135.9	78.1	30.6	14
Jérémie	93.7	102.1	70.8	109.0	166.8	130.2	88.1	105.1	115.2	110.4	124.9	58.8	12 and 13
Léogane	20.6	52.1	92.2	137.0	153.6	116.9	84.7	140.2	137.8	91.9	63.2	56.5	7 and 8
Limonade	31.2	70.1	66.3	136.7	86.0	54.9	26.8	72.8	104.2	177.9	229.6	79.9	4 and 5
Mateux	0.0	32.5	157.3	69.5	382.2	270.8	98.5	103.2	112.6	254.5	69.6	0.0	1
Miragoâne	33.5	40.0	54.1	109.3	205.6	107.4	155.2	134.3	203.7	165.6	68.1	49.1	10 and 11
Mirebalais	17.4	51.2	84.7	166.1	367.6	327.2	301.0	361.5	397.7	322.9	157.2	65.1	10
Môle St.-Nicolas	46.5	32.4	25.8	26.1	59.7	24.8	26.0	39.2	72.5	79.8	67.7	32.9	14 and 15
Moron	82.8	57.9	82.4	215.8	302.5	178.7	140.5	178.6	225.9	276.2	247.1	146.2	7-9
Pétionville	28.9	40.2	92.2	183.2	220.6	111.5	77.7	120.4	192.6	162.3	71.8	26.1	20 and 21
Petit-Goave	15.9	42.5	49.1	129.4	222.9	137.9	107.5	136.6	139.5	86.9	63.4	28.1	13 and 14
Pilate	58.6	63.7	74.1	168.2	261.7	169.1	123.7	170.7	172.2	171.3	235.3	72.8	7
Port-au-Prince (St.-Martial)	28.9	58.1	95.6	168.7	249.4	106.2	74.7	138.7	192.6	177.9	89.7	35.6	38
Port-au-Prince (Lalue)	26.2	53.6	122.9	177.2	201.2	119.2	71.4	137.5	200.1	181.1	108.4	38.8	13
Port-au-Prince (Ferme-Ecole Thor).	46.8	33.2	34.9	157.6	99.0	51.4	107.5	23.2	132.8	91.2	109.8	11.7	1
Port-de-Paix	143.6	82.9	43.3	71.5	71.9	90.9	50.2	95.5	146.6	129.3	234.7	140.6	13
St.-Marc	11.0	19.2	13.1	138.5	144.9	143.8	133.1	120.9	140.8	107.6	27.3	9.9	8 and 9
St.-Michel de l'Atalaye	10.9	6.5	33.6	76.1	172.2	215.5	119.0	163.7	144.8	118.5	75.3	31.4	12
Thomazeau	8.7	22.9	34.9	95.4	142.8	65.5	64.5	73.9	124.6	132.7	80.9	12.9	14 and 15
Tiburon	42.9	17.1	58.4	122.7	62.6	7.1	34.1	49.9	114.0	98.7	100.6	25.1	5-7

Mean annual rainfall.

Place.	Millimeters.	Place.	Millimeters.
Anse-à-Veau	1,061.7	Léogane	1,153.5
Arcahaie (l')	793.9	Limonade	1,136.4
Bahon	1,273.4	Miragoâne	1,329.0
Bainet	1,445.2	Mirebalais	2,659.4
Bassin-Bleu	986.1	Môle St.-Nicolas	542.4
Bayeux	2,109.2	Moron	2,124.8
Borgne (le)	1,728.2	Pétionville	1,326.8
Cap-Haïtien	1,584.4	Petit-Goave	1,159.7
Cayes (les)	2,107.6	Pilate	1,741.3
Chardonnières	582.0	Port-au-Prince (St.-Martial)	1,416.1
Dondon	1,974.1	Port-au-Prince (Lalue)	1,437.6
Fond-Verrettes	1,238.8	Port-de-Paix	1,282.7
Gantier	852.8	St.-Marc	910.1
Gonaïves	524.0	St.-Michel de l'Atalaye	1,167.2
Grande-Rivière du Nord	1,429.4	Thomazeau	859.7
Jacmel	1,205.6	Tiburon	733.2
Jérémie	1,266.3		

Colonial records of annual rainfall according to Moreau de Saint-Méry.

Place.	Millimeters.[a]	Years of record.
Bombardopolis	783	12
Croix-des-Bouquets	861	2
Fort-Liberté	1,510	Several
Léogane	1,350	20
Le Trou	1,473	4
Montagnes de Plymouth (Southeast of Jérémie)	4,485	1
Port-au-Prince	887	1
Port-Margot	3,804	2
St.-Louis (du Sud)	2,295	6

[a] Converted from feet on assumption that 1 foot equals 324 millimeters.

The seasonal distribution of rainfall is much more readily apparent in the curves shown in Figure 3 than in the tables. These curves, which cover 13 stations that probably are fairly representative of rainfall at low altitudes over the whole Republic, show that the spring rains generally last through April, May, and June and reach their maximum intensity usually in May. The fall rains come at a more variable date at different stations, ranging from August to December, and the average maximum is reached in the months of October and November. December to February, inclusive, are the dry winter months, and July is almost always the driest summer month. The fall rainy season is generally longer than the spring rainy season, and the winter dry season is longer than the summer dry season.

Unfortunately none of the stations for which records are available are at altitudes that represent the conditions on the higher mountain ranges. Fond-Verrettes, which is about 810 meters above sea level, is the highest

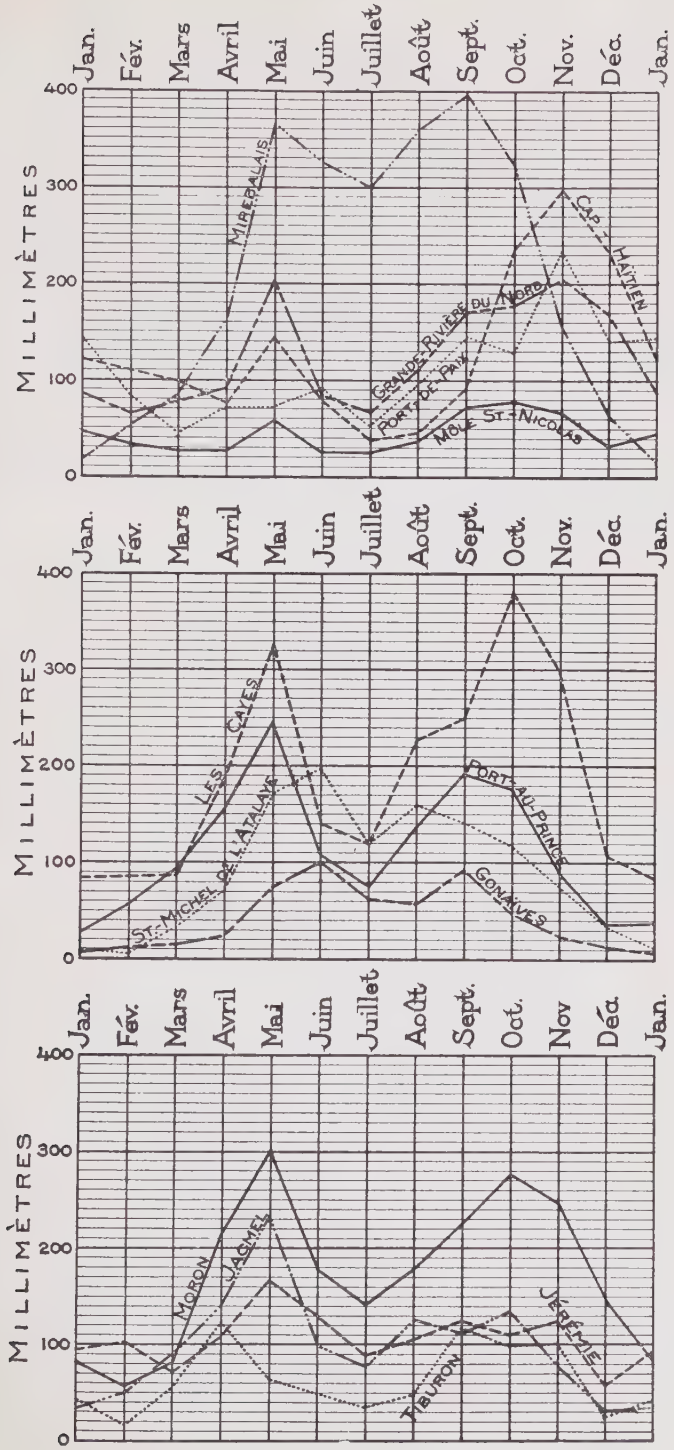


FIGURE 3.—Curves showing monthly mean rainfall for different stations.

station given in the tables. It has only a moderate yearly precipitation. Pétionville, at an altitude of 400 meters above sea level, has a slightly lower precipitation than Port-au-Prince, only 7 kilometers distant and near sea level. The heaviest precipitation, 2,659.4 millimeters, is at Mirebalais, an inland station only 100 meters above sea level. The lowest recorded precipitation, 524 millimeters, is at Gonaïves, which is only 3 meters above sea level. Other stations of very heavy annual precipitation, such as Les Cayes and Bayeux, are on the coast practically at sea level. The figures do not seem to signify any clear relation between altitude and amount of precipitation. The types of vegetation suggest that the most arid areas are the lowlands, such as the Artibonite Plain, Arbre Plain, and Cul-de-Sac Plain, but their aridity may be due in part to difference in temperature rather than to deficiency in rainfall.

The following table gives the available records for Furcy, the only station that stands at a really high altitude (1,540 meters), and the records for Port-au-Prince during the same periods.

Comparative rainfall in millimeters at Port-au-Prince and Furcy.

Date.	Furcy.	Port-au-Prince.
July 31 to Sept. 12, 1906	246.3	250.2
July 27 to Sept. 15, 1907	271.2	149.2
July 28 to Sept. 16, 1908	303.2	216.9
Aug. 1 to Sept. 15, 1909	645.2	282.2
Aug. 1 to Sept. 16, 1910	412.0	385.7
July 27 to Sept. 14, 1911	298.7	162.5
Aug. 3 to Sept. 18, 1912	353.8	278.3
July 29 to Sept. 17, 1913	374.4	184.8
July 23 to Sept. 14, 1914	224.4	343.2
July 21 to Sept. 16, 1915	532.0	301.0
July 28 to Sept. 13, 1916	438.8	102.5
July 26 to Sept. 15, 1917	381.4	384.2
Total	4,481.4	3,040.7
Dec. 1-31, 1907	17.3	0.5
Dec. 24, 1912 to Jan. 4, 1913	0.0	4.6
Dec. 24, 1913 to Jan. 4, 1914	0.0	0.0
Dec. 23, 1914 to Jan. 3, 1915	5.4	1.7
Dec. 28, 1915 to Jan. 3, 1916	4.6	1.4
Total	27.3	8.2

These figures seem to indicate that the rainfall at Furcy is nearly 50 per cent greater than that at Port-au-Prince, but it is not known whether the rainy seasons at the two places are synchronous and the results therefore can not be regarded as conclusive. Moreau de Saint-Méry states repeatedly that there is greater precipitation in the mountains than in the plains. Vallière, he says, is much wetter than Fort-Liberté. He estimates the yearly rainfall in the mountains back of Le Trou at an average

of 2,320 millimeters, about 60 per cent greater than that at Le Trou. His figures for Bombardopolis give a particularly valuable comparison with Môle St.-Nicolas, indicating nearly 50 per cent greater precipitation on the plateau near Bombardopolis. In general, it seems that the precipitation on the mountains may average 50 per cent more than that in the lowlands.

The controlling feature of the rainfall of the Republic of Haiti is the influence of its many mountain ranges on the moisture-bearing trade winds in the paths of which it lies. The general direction of these trade winds in the West Indian region is northeasterly, but over the Republic of Haiti they appear to incline somewhat more to the east. These winds, when they strike the high ridge of the Massif du Nord from Ouanaminthe to Port-de-Paix, deposit the greater part of their moisture on the northeastern slope of these mountains and the adjacent North Plain. Thus dried and rarefied they pass down the southwestern slope of these mountains and across the Central Plain and the Gonaïves Plain, and this region becomes increasingly arid as its altitude decreases.

These winds appear to come so nearly from the east that the whole of the Northwest Peninsula is in their lee and consequently that area is much more arid than its exposed position would suggest. Only on the northern slopes of its highest ranges is there enough rain to support forest growth and to raise crops without irrigation. The entire bordering lowland and much of the western plateau are arid or semiarid.

The winds that have crossed the Massif du Nord or the contiguous heights of the Dominican Republic and the Central Plain, sweep on across the Montagnes Noires, the Chaîne des Mateux, and their connecting ranges. The summits of these mountains are at some places high enough to cause considerable further condensation and to produce rainfall to support forests and garden crops. But the leeward lowlands, the lower Artibonite Plain and the Cul-de-Sac Plain, are arid or semiarid, and cultivation is there impossible without irrigation. The upper part of the Artibonite Valley appears to be so narrow that it shares the precipitation condensed by its surrounding mountains, and Mirebalais therefore has the highest rainfall of any station on record.

The Massif de la Selle, although it contains the highest peak of the Republic, does not appear to have the most abundant rainfall, because the winds have been robbed of so large a share of their moisture before reaching it. As compared with the Cul-de-Sac Plain and the south coast, however, it receives relatively high precipitation.

West of the Massif de la Selle the Southern Peninsula seems to receive more and more rain as it projects farther and farther beyond the shelter of the northern and eastern parts of the island of Haiti, and in the latitude of Jérémie it is one of the best-watered parts of the Republic. Here, as elsewhere, the north coast gets more rain than the south coast, much of

which is in fact rather arid with the one peculiar exception of Les Cayes. Perhaps the anomalously high rainfall at Les Cayes may be explained in part by the fact that although it is on the lee side of the main body of the peninsula it is also on the windward side of the mountainous projection that terminates in the Port-Salut Peninsula.

The precipitation comes in rainstorms of two very different types. The period from October to March is the season of "nords"—slow and steady rains of long duration borne by northeasterly winds. These rains may last from several hours to as much as two or three days. Few of these rainstorms yield a very large quantity of water. They are particularly characteristic of the north coast from Port-de-Paix eastward and in the western part of the Southern Peninsula. They raise the winter rainfall at Cap-Haïtien, Bayeux, Le Borgne, Port-de-Paix, Grande-Rivière du Nord, Jérémie, and Moron above that of the other stations.

The other type of rainstorm prevails in summer and is doubtless due to the northward migration of the equatorial storm belt at this season. Most of the rain in the drier parts of the Republic falls in violent storms of short duration, many of them accompanied by high wind, thunder, and lightning. Late in the summer many such storms, especially those on the south coast, become destructive hurricanes, causing great damage. Occasionally the country is swept by violent hurricanes, usually accompanied by heavy rain, which cause tidal waves that do great damage to shipping and to buildings on the water front. Especially destructive hurricanes occurred in August, 1909, and in August, 1915.

The long periods of unbroken drought at certain stations directly affect the population. At Môle St.-Nicolas, St.-Michel de l'Atalaye, and Jacmel two consecutive months of no rainfall have been recorded, and at Gonaïves, St.-Marc, and Thomazeau three consecutive months. A very great part of the rain at these stations comes in heavy storms. During the year 1919 at all the stations of observation 38 per cent of the total rainfall by months fell in single storms, although several rainy days usually were recorded each month. The intensity of rains is briefly summed up by Scherer[1] as follows:

> Nos pluies sont relativement courtes. La plupart durent moins d'une heure. Une pluie de deux heures paraît déjà longue. Rarement elles dépassent quatre heures. Une pluie de 12 heures ou de 24 heures est regardée comme extraordinaire. Elle suppose une perturbation atmosphérique. D'ailleurs ce ne sont pas les longues pluies qui fournissent beaucoup d'eau au pluviomètre. Généralement les courtes pluies sont aussi les plus intenses.

This characterization of the storms of the Republic corresponds with a further statement by Scherer in the same article: "Chez nous les pluies sont plutôt locales que régionales."

[1] Scherer, J., Observatoire Météorologique du Séminaire-Collège St. Martial Bull. Ann., 1919, p. 99, 1920.

The hours of rain or the time of day at which rain is most likely to fall has also been determined by Scherer,[1] whose conclusions, based on records tabulated at many stations, are summarized as follows:

Avant d'examiner quelques tableaux en particulier, indiquons les points principaux sur lesquels doit porter la lecture. Ces points sont le minimum et le maximum de fréquence et l'amplitude, c'est-a-dire l'écart entre les valeurs extrêmes. Au bas de chaque tableau on consultera d'abord les totaux. On pourra constater vers les 9 h. ou 10 h. du matin un minimum de fréquence, commun presque à tout le pays. Les maxima indiqués dans les tableaux surviennent dans l'après-midi, à des heures différentes selon les stations, les uns plus repprochés de midi, les autres du coucher du soleil selon la région. D'autres stations, comme les Cayes et Jérémie, ont une phase double: deux minima et deux maxima nettement marqués.

Si l'on compare les résultats mensuels d'une même station, on constate d'une part un léger déplacement pour le minimum du matin et d'autre part pour le maximum une avance vers midi ou un recul vers minuit, suivant les saisons. En certains pays il pleut à peu près aux mêmes heures toute l'année; en d'autres, des pluies tardives semblent coincider avec l'affaiblissement du régime pluvieux annuel.

Hail, usually accompanying summer thunderstorms, is fairly common in the Republic, and many hailstorms are noted in the bulletins of the Observatoire Météorologique. They seem to have been very common at St.-Michel de l'Atalaye. Moreau de Saint-Méry speaks of hailstones "as big as the fist" which fell at Fort-Liberté on June 17, 1785, and as large as pigeons' eggs at Boucassin May 30, 1786. Such hailstorms do much damage to growing crops.

Relative Humidity.

The relative humidity appears to vary within wide limits. It is very different for different localities at the same time, and for the same locality at different times of the day, although the monthly means vary but little from year to year. The humidity is rarely so great anywhere as to cause great physical discomfort. It is probably less than in many tropical regions, so that the warm climate is more endurable. Observations of relative humidity at Port-au-Prince covering many years give the following monthly means: January, 65; February, 63; March, 64; April, 69; May, 73; June 68; July, 64; August, 68; September, 73; October, 75; November, 72; December, 68.

These figures show a marked correspondence of high humidity with the rainy seasons and of lower humidity with the dry seasons.

The daily fluctuation of relative humidity at Port-au-Prince usually covers a range of 30, the minimum being about 50 at midday and the maximum about 80 sometime between midnight and 4 a. m. The following table of hourly means for the year 1910, is characteristic of the daily range of humidity at this station:

[1] Idem., p. 100.

Hourly mean humidity at Port-au-Prince, Haiti, in 1910.

1 a.m. 82.9	9 a.m. 63.5	5 p.m. 65.9
2 a.m. 83.3	10 a.m. 56.8	6 p.m. 71.3
3 a.m. 83.6	11 a.m. 52.0	7 p.m. 75.7
4 a.m. 83.4	12 m. 50.6	8 p.m. 78.2
5 a.m. 83.2	1 p.m. 52.8	9 p.m. 79.8
6 a.m. 82.7	2 p.m. 56.9	10 p.m. 81.5
7 a.m. 79.4	3 p.m. 60.4	11 p.m. 82.2
8 a.m. 71.3	4 p.m. 62.9	12 p.m. 82.4

The average for this year, 71.8, is somewhat higher than the general yearly average, which is about 68.5.

The only other station for which records of observations are published is Furcy, and these records like the records of temperature, are incomplete. For the midsummer period, including August and parts of July and September, the mean, based on observations at 7 a. m., 1 p. m., and 9 p. m., is 80, and for the Christmas or New Year period the mean is 78. These figures show that the humidity at Furcy is considerably higher than that at Port-au-Prince. Humidity above 90 appears to be common at Furcy, and the climate there would be very uncomfortable if the temperature were higher.

Winds.

As the Republic lies in the belt of northeast trade winds its prevailing winds are from the northeast or east. Along the northern coast they blow very nearly from the east, probably because they are deflected in that direction by the configuration of the land. The same deflection may occur in Cul-de-Sac Plain. These winds are steadiest and most unvarying in direction in winter. In summer, as the equatorial belt moves northward, they are often replaced by local and variable storm winds.

The trade winds are locally much modified and obscured by the daily land and sea breezes of the coast. Few parts of the Republic except, perhaps, the Central Plain, are far enough from the sea to be beyond their influence. For this reason very strong and persistent winds from one direction, such as cause the accumulation of wind-blown sand and produce marked asymmetry in the growth of vegetation, are uncommon in the Republic. In general the sea breezes blow at right angles to the coast and the land breezes blow directly out to sea, but each shows a strong tendency to veer somewhat to the east, probably in conformity with the prevailing direction of the trade winds. Thus on the south coast the land breezes usually come from the northeast and sea breezes from the southeast.

The land and sea breezes do much to mitigate the tropical heat. When the sea breeze fails for a day in summer, as it does occasionally at Port-au-Prince and elsewhere, the heat is very oppressive. Moreau de Saint-Méry says that at Croix-des-Bouquets the sea breeze has failed for as much as three weeks consecutively. On the coast the breezes generally are very regular and determine the hours of sailing of small vessels engaged in fishing and coastwise traffic.

VEGETATION.

Types of Vegetation.

Although the Republic is a tropical country it includes only a few small areas where the vegetation presents the aspect of an impenetrable tropical rain forest, the aspect that is so commonly visualized by one thinking of a tropical region. Differences in rainfall, soil, and altitude cause the vegetation to change constantly within remarkably short distances. The indigenous flora is very rich in species and has been little studied. The observations recorded here are intended only to give an impression of the general features of the vegetation, of the relation of the vegetation to the geology and the climate, and of the possible value of the forests. Most of the area of the Republic is covered by two contrasted types of vegetation—the mesophytic type, which is developed where rainfall is normal or abundant and which includes most of the forests, and the xerophytic or desert type which prevails in areas of slight rainfall. There are in addition small but significant areas of halophytic and of shoreline vegetation.

Forests.

OCCURRENCE AND GENERAL APPEARANCE.

The forests of the Republic are generally, though not uniformly, confined to the mountainous areas. As the northeast slopes of the mountain ranges receive much more rainfall than the southwest slopes, they are more heavily wooded and bear forests at much lower altitudes. Everywhere, however, the forest growth becomes thinner and more stunted toward the base of the mountains. The forests visible from the sea are therefore generally rather scrubby in appearance and do not give a fair impression of the country as a whole. Probably none of the forests anywhere fairly represents the beauty and the extent of those that existed before the discovery of the island. During the days of the French colony large areas were cleared to make room for plantations of coffee, cacao, and other crops, and such clearing, frequently assisted by fire, has been continued to some extent ever since. Valuable wood in accessible localities has been exploited commercially during and since colonial days. Finally, the cutting of firewood and the burning of charcoal, the only natural fuels available, cause a continued and enormous wastage. It is therefore not surprising that virgin forests, if they occur at all, are found only in the most remote and inaccessible localities.

KINDS OF TREES.

The writers are familiar with the names of only a few of the more common and conspicuous trees. The native oak (bois de chêne), the tavernon, and the sandbox tree (sablier) are among the larger and more handsome forest trees. The silk cotton tree (arbre à coton) reaches a

large size. Large areas in the Southern Peninsula contain a tree that resembles the American walnut. Most of the forests at moderately high altitudes contain large trees of the West Indian cedar (acajou senti). Pines are found on some of the mountain tops and under exceptional conditions on the plains. The royal palm (palmier royal), with its great green head surmounting a clean slender trunk from 10 to 18 meters high, is one of the most graceful trees of the Republic. It grows at moderate or low altitudes where the soil retains moisture fairly well. Fan palms (palmiers à éventail) are confined to low altitudes, usually on calcareous soils. Both the base of the fronds of palms (tache) and the fronds are used as roofing material. The coconut palm (cocotier), which is very common at low altitudes, is generally a cultivated tree. The calabash tree (calebassier) bears on its trunk great green fruits resembling gourds, which are much used for water vessels and bowls. The largest tree in the Republic is the mapou, which at some places attains a diameter of nearly 3 meters. (See Pl. IV, *A*.) It grows singly at moderate or low altitudes where the climate and soil are not excessively dry. At many localities, especially where the rainfall is not excessive, leguminous trees and shrubs are numerous. The coral bean tree (bois immortel) is used to make living fences. The trumpet tree (bois trompette) is grown as an ornamental tree around houses, especially in the Southern Peninsula.

Many of the native fruit trees are common in the forests. Among them are the alligator pear (avocatier), sour sop (corossolier), sapote (sapotillier), mammee tree (abricotier), sweet sop (pomme cannelle or cachiman cannelle), custard apple (cachiman crème and cachiman coeur-de-boeuf), star apple (caimitier), and the native cherry (cerisier). Several fruit trees from other tropical countries have also spread over the island and many of them grow wild in the forests. Among them are the orange (orange), lime (citron), grape-fruit (shaddock), bread-fruit (arbre-à-pain), mulberry (murier), guava (goyavier), and mango (manguier). The mango grows singly or in clusters spaced at ample intervals. Its wide, rounded tops bear an impenetrable canopy of dark-green leaves, making it one of the best and most handsome shade trees of the country.

The Republic contains valuable cabinet woods, especially mahogany (acajou), but the supply of mahogany has now been so greatly depleted that only a small production from isolated and more or less carefully guarded trees is possible. Some mahogany is used locally and some is exported. Other valuable cabinet woods are the manchineel (mancenillier), satinwood, rose wood (bois rose), cinnamon wood (bois cannelle), yellow acoma (acoma jaune), a kind of ebony (ébène), and gris-gris. Lignum vitae (gayac), a very hard wood that is in special demand for making tools and parts of machines, is exported in large quantities when trade conditions are favorable. Dyewoods, especially logwood (campêche), have been exported on a large scale. Logwood is not indigenous but was intro-

A. MAPOU TREE IN MEMÉ VALLEY NEAR TERRE-NEUVE.

B. XEROPHYTIC VEGETATION IN THE ARTIBONITE PLAIN SOUTHEAST OF GRANDE-SALINE.

Principally cactus and bayahonde.

duced in colonial days and has spread rapidly over the Republic, where it grows best in dry, calcareous soils. Brazil wood (brésillet), fustic (fustet), and sassafras are other dyewoods.

ASSOCIATED VEGETATION.

Associated with the forest trees at high altitudes (above 1,000 meters) there are many ferns (fougères), tree ferns (fougères arborescentes), and a great variety of underbrush. The tree ferns and begonias are especially characteristic of areas of volcanic rocks at high altitudes. At lower altitudes bamboo (bambous) and heliconias (bananier marron) are found in moist ground along streams. Bamboo grows in dense clusters to a height of 20 meters and a diameter of 10 or 15 centimeters. The hollow stalks are cut in lengths of about 2 meters, the ends are plugged up, and the hollow pipe thus made is used for carrying water. Bamboo has been introduced from the orient, but there are several similar indigenous plants. The trees at all altitudes contain a large number of epiphytic bromeliads and orchids. A great variety of lianas (lianes) festoon the trees at all altitudes. Some of the striking lianas are the barrel liana (liane à barrique), which is used in making barrel hoops, the water liana (liane-à-l'eau), which yields potable water, the snuffbox sea bean (liane coeur-de-St. Thomas), and ox-eye sea bean (liane à cacone or yeux de bourrique). The seeds of the snuffbox sea bean and ox-eye bean are the most common West Indian seeds that are carried by the Gulf Stream to the shores of northeastern Europe.

Low down on the mountain slopes the forests are replaced by xerophytic plants and grasses. On the northeastern slope of the Massif du Nord and in the northwestern part of the Southern Peninsula trees and shrubs that are elsewhere found at high altitudes extend down to unusually low altitudes.

NOTES ON LOCAL AREAS.

The uncultivated land in the Massif du Nord is generally rather heavily forested on the crest and well down on the northeastern slope. The southwestern slope, facing the Central Plain, and the lowlands of Gonaïves are invaded by xerophytic vegetation. The crest of the limestone ridge northeast of the Central Plain is covered with thick, scrubby forest, but north of Cerca-la-Source the vegetation changes abruptly to an open pine forest with short brown grass and little underbrush except in ravines. This vegetation gives way to dense forests with much underbrush and no pines along the crest of the divide between Lamielle and Mont Organisé, perhaps owing to a difference in precipitation, as there is no apparent difference in soil. In the vicinity of Mont Organisé, however, there is open pine forest, and scattered pines extend down into the edge of the North Plain at an altitude of 100 meters above sea level, the lowest alti-

tude at which they were seen anywhere. Here they are confined to ravines. Pines are common as far to the west as Dondon, but in all this region they are confined to areas of igneous or metamorphic rock. The valleys of Grande Rivière du Nord, Dondon, and those to the west contain magnificent sandbox (sablier) and mapou trees, most of them in waste corners and along fence rows, for the land is cultivated.

Only the summits of ranges and some of the mountain valleys in the Northwest Peninsula are much forested. The tavernon, mapou, and mango are conspicuous trees in the valleys. There is a small stand of particularly large trees in the valley west of Terre-Neuve. Pines grow only on the crest of a range just north of the Sources Chaudes. The other trees are said to include many valuable species. Mahogany appears to be restricted mainly to the lower mountain slopes. There are many isolated trees in the Commune of Gros-Morne but they could not be extensively exploited. The Bombardopolis Plateau contains large areas of very dense forest, apparently new growth, and a great deal of lignum vitae (gayac), which, however, is kept down by constant cutting, for it is the chief article of export at Môle St.-Nicholas.

The limestone ridges of the Montagnes Noires are generally thickly timbered, but large and perfect trees are confined to small areas. At places forests extend into the Central Plain. The trough at the foot of the mountains on the southwest and south margins of the plain supports a heavy forest, as does also the depression southeast of Rivière Canot, just northwest of Maïssade. A peculiar feature of the Central Plain is the occurrence of pines along certain ridges about its edge and in the interior between Maïssade and Pignon. These ridges mark the outcrop of folded beds of coarse sandy rock that appears to furnish a soil especially suited to the pines.

The sides of the Chaîne des Mateux bear only scrubby brush, and most of its crest is a grassy or bushy savanna. Guavas are thick and attain almost the dignity of trees. Northeast of Couyau and elsewhere there are considerable areas that have a thin stand of pines, which grow in tall guinea grass. Farther southeast the conditions are much the same, and there is little forest. Grands-Bois, or Cornillon, gets its name from the forests which once existed there. Moreau de Saint-Méry states that the forests were cut down in colonial days to make room for coffee.[1] Several years ago pines and other trees from this region were cut into lumber at a sawmill at Glore, on the northern shore of Étang Saumâtre, but the mill has burned down. There is now only a thin stand of pines in this region. The pines of the Chaîne des Mateux and Grands-Bois grow on limestone, and are virtually confined to altitudes of 1,000 meters or more above sea level.

[1] Op. cit., vol. 2, pp. 294 et seq.

The higher uncultivated parts of the Massif de la Selle are generally forested. The lower slopes contain merely brush. Along the Dominican border, south of Fond-Verrettes (also called Mission), scattered pines grow on a limestone terrane from an altitude of about 1,000 meters up to 1,400 meters above sea level, where they give way to a dense tropical rain forest. Above 1,600 meters, however, an open pine forest in a thick stand is found again. This pine forest extends up to the very peak of Mont La Selle. On the south slope, from 1,500 meters down to 1,000 meters, the belt of the tropical rain forest is strongly developed and grades into xerophytic vegetation lower down, near the south coast. Similar conditions are found at corresponding altitudes farther west. Near Furcy there is a large area of depleted pine forest, some of it on limestone but most of it on basaltic rock. The summit of the divide between Jacmel and Port-au-Prince, at an altitude of about 1,300 meters above sea level, supports a dense tropical rain forest. The limestone lower down on the north side of the mountains contains many trees but no real forest.

The mountains of the Massif de la Hotte, particularly the Montagnes de la Hotte and their northern slopes, in some places even down to the coast, bear heavy forests that probably contain valuable species. The vicinity of Baradères Bay was one of the most famous lumbering regions of colonial days, but the virgin forests of the present day are confined to the interior, and roads would have to be made to exploit them. There are practicable routes up the valleys of the Grande Rivière de Jérémie, the Rivière de Tiburon, the Rivière des Baradères and the Grande Rivière de Nippes. The route up the Grande Rivière de Nippes would tap the rich agricultural land of the Asile Valley. This area probably offers the best opportunity for the development of the lumber resources of the Republic, and it is at least worthy of a survey by a qualified forester.

Gonave Island contains no extensive forests. Large isolated mahogany trees are found in the interior of the island. All the upland is covered with thick shrubbery except areas that were cleared and have grown up in guinea grass. The inclosed lowland called the Plaine des Mapoux gets its name from some large mapou trees.

The forests of Tortue Island were famous in colonial days and were then extensively exploited. Moreau de Saint-Méry states that nearly all the valuable species of the colony grew there, among them mahogany, gayac, and bois-marie or dame-marie.[1] At present the eastern end of the island is partly cleared, and large areas in it are abandoned to guinea grass. The western third and most of the northern slope are forested. During a brief visit to the region near Vallée our party saw some gris-gris but no mahogany. A few years ago a Belgian company attempted to exploit the timber on this island by building a narrow-gage railway northward from Vallée. The grade was established, a little track was laid, and

[1] Op. cit., vol. 1, p. 740.

two locomotives were installed, but they are now idle, and no timber appears ever to have been cut by the company.

Logwood has been exploited with more success in recent years than any other forest product. At Grande-Rivière du Nord a plant for the extraction of dye liquids was operated for several years. It burned down but has now been replaced. This plant is supplied mainly from groves of logwood on the north side of the Central Plain near St.-Raphaël and Pignon. At Port-de-Paix a remarkable aerial tramway has been constructed to convey logwood a distance of about 18 kilometers from Bassin-Bleu to the coast. The supply is drawn from the slopes of the valley of Les Trois Rivières but is said to be very much depleted. Good groves of logwood were seen in the valley of the Artibonite southeast of La Chapelle. There is much logwood along the south coast, and it is exported in considerable quantity from Miragoâne.

Figures showing the export value of different forest products are given under the heading "Commerce" (p. 79).

Xerophytic Vegetation.

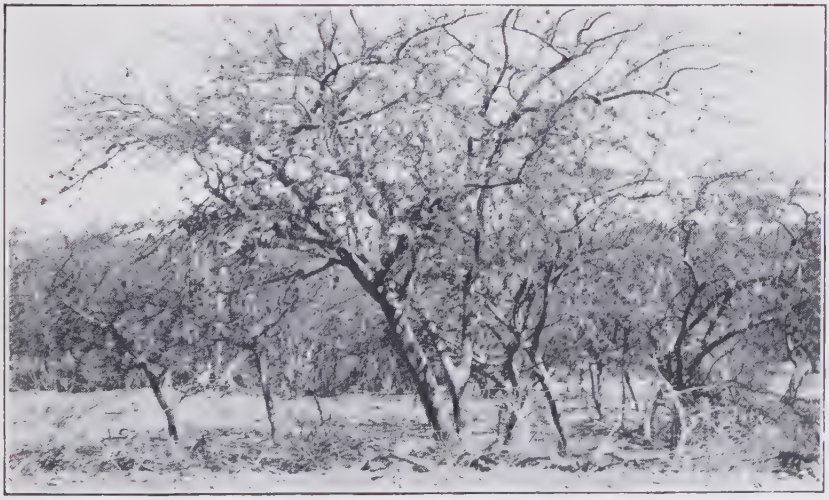
EXTENT AND GENERAL FEATURES.

The xerophytic vegetation of the Republic is typical of its plains, particularly the arid plains in the lee of the mountain ranges, such as the Cul-de-Sac, Artibonite, and Arbre plains. The vegetation at some places on these plains is of an extremely arid type. The xerophytes usually extend some distance up the mountain slopes, especially the southwestward-facing slopes, where they even approach the crests of high ranges, as at Ennery. They include innumerable spiny plants, among which cacti are prominent and at some places dominant. The general aspect of these arid plains is sterile and forbidding, and their great extent, particularly over the more accessible parts of the Republic, is unpleasantly surprising to travelers who see the country for the first time.

KINDS OF PLANTS.

The cacti are the dominant plants in extremely arid regions. There are numerous kinds of cacti, many of which seem to be similar to species found on the mainland of North America. Arborescent forms are wonderfully developed and some of them attain a height of 6 or 10 meters and have trunks more than 30 centimeters in diameter. Cacti are especially typical of the northwestern part of the Cul-de-Sac Plain, the lower Artibonite Plain, and the vicinity of the Arbre Plain (Pl. IV, *B*). Certain kinds of cacti, particularly opuntias (raquettes), are widespread and are not confined to the typically arid regions. Columnar cereus is used for hedges at many localities outside the zones of xerophytic vegetation. Opuntias, associated with pine forests, are reported from Mont la Selle, the highest peak in the Republic.

A. BAYAHONDE THICKET IN THE CUL-DE-SAC PLAIN NEAR PONT BEUDET.



B. THICKET OF *CERCIDIUM PRAECOX* (A PALO VERDE) ABOUT 5 KILOMETERS NORTHEAST OF GONAÏVES ON THE TRAIL TO TERRE-NEUVE.

Cacti are not by any means the only plants of the xerophytic regions. Where the soil is fertile and retains moisture well large areas of the plain are forested with a thick tangle of bayahonde, a scrubby leguminous tree resembling the American mesquite (Pl. V, *A*). This wood is hard and takes a good polish. The trunks of some of these trees reach a diameter of 0.6 meter, but they are knotty and gnarled. The bayahonde is used a great deal for fuel, some of it as charcoal. It is interesting to note that a small palo verde, a tree that has not been previously reported from the Republic, was found on the desert plain north of Gonaïves, on the trail to Terre-Neuve. Mr. Paul C. Standley, of the United States National Museum, reports that it is probably *Cercidium praecox,* the Mexican species. (See Pl. V, *B*.) Acacias, yuccas, and agaves, of different kinds, as well as palmettos, grow on the mountain slopes. Many palmettos rise somewhat above the other trees and are spaced at intervals so regular that they give the landscape the aspect of a weird orchard. Palmettos are characteristic of transition zones between the xerophytic and mesophytic vegetation. Certain species furnish material for baskets, and the aloes furnish fibers for rope, two articles that are manufactured and used locally in great quantities. Many of the trees and shrubs in the xerophytic zones are covered with masses of *Tillandsia* and other bromeliads, as well as with other epiphytic plants. Agaves are at many places used as hedges.

Savannas.

Grassy savannas are numerous and at places extensive. Some of them, particularly those on the plains, are natural prairies; others, especially those in the mountains, occupy land that was cleared for agriculture and abandoned. Most of the cleared areas are covered with guinea grass, but the natural savannas are covered with native grasses. The grass in the more humid areas is often 0.5 to 1 meter tall, but throughout most of the year it is rather dry and brown, especially on the natural savannas. Where stock raising is feasible it is often eaten down.

The savannas of the plains are most extensive on the North Plain and the Central Plain. On the North Plain there is a belt of savanna 4 or 5 kilometers wide at the base of the mountains from Les Perches to Ouaminthe. The savanna is very flat except where it is dissected by narrow, steep-sided ravines. In the ravines there is a healthy forest growth, including pines, but elsewhere there is scarcely anything but grass. At its northern border the savanna grades into a lowland covered with xerophytic shrubs, probably because rainfall is less abundant at this distance from the mountains.

The northwest part of the Central Plain is a flat, grassy savanna, in which there are a few ravines that contain a growth of shrubs and small trees which causes them to stand out as sinuous green lines in the general expanse of brown grass. Southeast of this large savanna the plain is more

dissected and consequently more wooded. The interstream areas are grassy, but are invaded by a shrub resembling greasewood. In this region there are a few areas of pine and other forest trees. (See p. 60.)

Smaller savannas of this general type are seen in the Artibonite Valley near Mirebalais and farther down the valley, as well as in the uper part of the Cayes Plain.

Savannas of a second type, which occupy areas once forested, are found in the Massif du Nord, particularly in the Chaîne des Mateux and its connected ranges to the east. They are found also in the Massif de la Selle, and on Tortue and Gonave islands. They generally occupy fairly flat or rolling uplands, not the steep and rugged mountain sides. The grassy savannas are associated with a thin stand of pines. (See pp. 59-60.)

A third type of savanna is found in areas of volcanic rock, particularly in the southern two-thirds of the Republic. These areas, especially the areas of basalt, where the rainfall is not very great, are covered with short brown grass (Pl. VI, *A*) and present a strong contrast to the adjacent areas of limestone, which are densely wooded, although all the forests do not contain large trees. Contrasts of this kind are very common throughout the Southern Peninsula and near Saut d'Eau, on the north slope of the Chaîne des Mateux.

A similar contrast may be observed between areas of the rather impervious chalky limestone and areas of the more massive and porous limestone. The areas of chalky limestone support only low shrubs and flowering plants and a growth of short grass resembling that of the areas of volcanic rock. The areas of massive limestone are forested or are covered with tall guinea grass. This contrast was noted at places on the mountains north of Ennery, on Gonave Island, and on the south slope of the Southern Peninsula, in the region between Jacmel and Côtes-de-Fer, where the chalky limestones are extensively exposed.

Halophytic Vegetation.

On the lower Artibonite Plain, where the soil is poorly drained and very alkaline, there is an extensive area of halophytic vegetation, in which a variety of salt bush is particularly abundant. (See Pl. VI, *B*.)

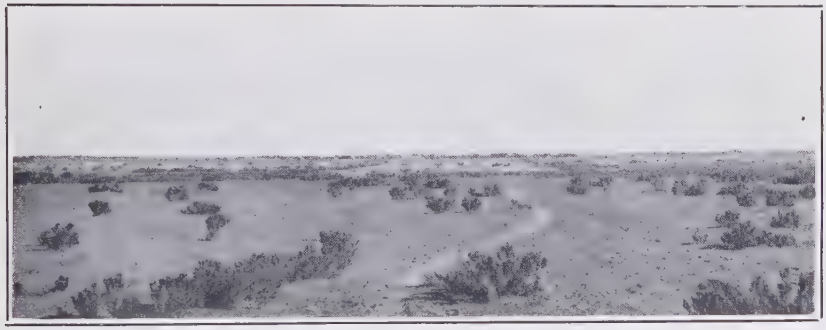
There are regions of similar vegetation near the sea at the west end of the Cul-de-Sac Plain and at the outer edge of many other smaller coastal plains. Plate VI, *C*, shows the halophytic vegetation on a mud flat behind a lagoon and mangrove thicket on the north coast of Gonave Island west of Étroit. In all these areas the halophytes are replaced by xerophytes farther back from the shore.

Vegetation of the Shore Line.

Extensive mangrove thickets are conspicuous along the shore line of the low coastal plains, especially in the North, Artibonite, and Cul-de-Sac

A. SAVANE LA CIDRA, ABOUT 10 KILOMETERS SOUTHWEST OF ST.-MICHEL DE L'ATALAYE.

In some parts of the Republic grass-covered savannas are characteristic of areas floored with volcanic rocks.



B. SALT BUSH IN THE ARTIBONITE PLAIN NEAR GRANDE-SALINE.

Characteristic of alkaline soil.

C. HALOPHYTIC VEGETATION ON THE NORTH COAST OF GONAVE ISLAND WEST OF ETROIT.

In the background, between the sea and a lagoon, is a mangrove thicket.

plains. The thickets are composed of several kinds of mangroves (mangliers or paletuviers), which are called red mangrove (manglier rouge or manglier chandelle), gray mangrove (manglier gris), and black mangrove (manglier noir). These trees supply firewood and tan bark.

Among the plants and trees that are conspicuous on beaches where there are no mangrove thickets are seaside grape (raisinier bord-de-mer), seaside potato (patate bord-de-mer), and manchineel tree (mancenillier), which has a poisonous fruit.

ECONOMIC GEOGRAPHY.

POPULATION.

Total Population.

The favorable climate and the productive soil of the island have brought to it a dense population throughout most of its known history, which begins with its discovery by Columbus in 1492. At that time the number of aboriginal Indians in the whole island was estimated at from 1,000,000 to 2,000,000, the lower estimate probably being more nearly correct. Under Spanish rule, within a few decades after the island was discovered, this population was practically annihilated by war and slavery and was replaced gradually by African negroes, who were imported in great numbers in the eighteenth century, particularly by the French, who had taken possession of the western part of the island—the part that now constitutes the Republic of Haiti. Moreau de Saint-Méry,[1] the most trustworthy historian of the colonial period, estimates the total population of the French colony in 1788, near the close of the colonial era, at 520,000, of whom 40,000 were white, 28,000 were "people of color" ("gens de couleur"), and the remaining 452,000 were black. This population inhabited an area smaller than that of the present Republic, as the Central Plain and adjacent mountain slopes were then Spanish territory.

No reliable census of the Republic has ever been taken. War and famine and the exodus of the whites reduced the population considerably in the years during and immediately following the Revolution. Tippenhauer[2] regards Humboldt's estimate of 375,000 people in 1802 as reliable and considers conservatively some later estimates. Even the best estimates, which are probably those made by the clergy for church use, he regards as generally rather large. The clergy estimated the population in 1876 at 960,000 and in 1887 at 1,017,000, which Tippenhauer would reduce to 800,000 in 1880 and 900,000 in 1888. The latest ecclesiastical estimate in 1905 was 1,425,000, and more recent estimates range from 1,500,000 to 2,500,000. The former figure probably is more nearly correct.

[1] Op. cit., vol. 1, p. 5.
[2] Tippenhauer, L. G., Die Insel Haïti, pp. 420 et seq., Leipzig, 1893.

Principal Cities and Towns.

Port-au-Prince, the capital, which is by far the largest city of the Republic, had a few years ago a population that was conservatively estimated at 100,000. Very recently the population has grown so rapidly that it is now estimated by some of its inhabitants as high as 200,000, but perhaps 125,000 is a safer figure. Fortunat[1] placed the population in 1888 at 60,000, probably including all the commune, which, however, would not greatly increase the total for the city. The capital has not always been the largest city of the Republic, for in colonial days it was greatly overshadowed by Cap-Français (Cap-Haïtien). The population of Port-au-Prince in 1789, according to Moreau de Saint-Méry, was about 6,200, to which he adds a transient population of 3,200 sailors and soldiers. Cap-Français was about twice as large.

Cap-Haïtien, called Cap-Français in colonial days and Cap-Henri during the reign of Christophe, had 12,151 inhabitants according to the official census of 1788. Moreau de Saint-Méry thought this figure too low and estimated the resident population at 15,000 and the transients (soldiers and sailors) at 3,550. At all events the Cap was the largest and busiest city of the colony. At present it is not a great deal larger than it was then, for a census taken in December, 1918, is said to have shown 14,000 people. Conard,[2] however, thought the population was nearer 20,000. Fortunat gives 29,000 for the whole commune in 1888, but this appears to be rather high for the city proper.

Les Cayes, frequently called Aux Cayes in English literature, was the third largest city of the colony and probably still retains that position. In 1789, according to Moreau de Saint-Méry, it had 4,550 permanent and 1,100 transient inhabitants. The figure given by Fortunat for 1888 and still published in recent encyclopedias is 25,000, but this represents the population of the whole commune and includes many residents of the Cayes Plain. The population of the city proper probably is not over 15,000.

Conservative estimates of the population of other larger cities of the Republic are : Gonaïves, 12,000; St. Marc, 10,000; Jacmel, 10,000; Port-de-Paix, 7,500, and Jérémie, 7,500. All these cities are busy open ports. Among the other ports that have a population ranging from 500 up to a few thousand are Petit-Goave, Miragoâne, Anse-à-Veau, Dame-Marie, Aquin, St.-Louis du Sud, l'Arcahaie, Môle St.-Nicolas, and Fort-Liberté.

Among the inland towns whose population ranges probably from 5,000 down to about 1,000 are Mirebalais, Croix-des-Bouquets, Petite-Rivière de l'Artibonite, Grande-Rivière du Nord, Léogane, Gros-Morne, Hinche, St.-Michel de l'Atalaye, Las Cahobas, and Jean Rabel.

[1] Fortunat, Dantès, Nouvelle géographie de l'île d'Haïti, p. 349, Port-au-Prince and Paris, 1888.

[2] Conard, R. A., Report on water supply of Cap-Haïtien to Engineer in Chief of Republic of Haiti, April 2, 1919.

Comparison of Urban and Rural Population.

The estimated population of the larger cities as given above is summarized as follows:

Port-au-Prince	125,000	Jacmel	10,000
Cap-Haïtien	20,000	Port-de-Paix	7,500
Les Cayes	15,000	Jérémie	7,500
Gonaïves	12,000		
St.-Marc	10,000		207,000

Probably the people who live in other towns having a population of more than 1,000 would increase the total urban population to about 225,000, possibly even to 250,000. If the total population is 1,500,000 the percentage of city dwellers is about 15 to 17, figures which show that the population of the Republic is essentially rural and that agriculture is the chief industry.

Although the population is so largely rural and depends for its living mainly on the soil, much of it is concentrated in small villages and rural communities of a hundred people or less rather than in detached houses occupied by one family. Whenever possible the Haitians live in little communities, some of them consisting of only three or four families, and as each of these communities has a distinctive name, an almost infinite number of place names appear on the maps and in the literature.

Density of Population.

The area of the Republic is about 27,700 square kilometers. This figure includes the islands of Tortue, Gonave, and Vache, which belong to the Republic and are closely related to the main island geographically. If the total population is estimated as 1,500,000 or a little more the average density of population is about 55 to the square kilometer, but if the city population is omitted the average density for the rural regions is about 45 to the square kilometer. The rural population is, however, very unevenly distributed, and large areas that have unfavorable climate, soil, or surface features are virtually unsettled. The whole of Tortue Island, for example, is sparsely inhabited. Gonave Island has a small population, probably considerably less than 10,000, which is concentrated in little coastal villages and on small bodies of good agricultural land in the eastern half of the island. Ile-à-Vache and Grande Cayemite Island also have a relatively thin agricultural population.

The density of population in fertile, thickly settled parts of the Republic is undoubtedly double the figure given, or at least 100 to the square kilometer. The average density of population per square kilometer in France in 1910 was 78, in Germany 124, in Great Britain 154, and in the United States 12.

Geographic Features Influencing Distribution of Population.

There is a very natural concentration of the population on the long, crooked coast. All the larger cities are ports, which depend in great measure upon foreign commerce. Many smaller towns on the coast are not open to foreign trade, but they have extensive coastwise commerce, particularly as feeders for the larger ports. The almost impassable mountains and the general lack of roads greatly increase the volume of ocean travel and transportation. Moreover, many of the alluvial plains that constitute the bulk of the agricultural land border the shore and favor the concentration of population near the sea. Fishing also is an industry that provides both occupation and sustenance for a large number of the inhabitants of the coast. Some long stretches of coast, however, are unapproachable even by small boats and are unfit for cultivation, and are therefore very thinly inhabited.

Over the strictly agricultural regions the density of population is closely proportioned to the productivity of the land in articles of food and in the few staple export crops—coffee, cotton, sugar, and cacao. Although the forests at times supply a large part of the exports they are worked for the most part by labor drawn temporarily from near-by towns or agricultural regions.

The productivity of any part of the land depends on the surface features, the climate, and the soil. Closely related to the surface features is accessibility to markets. Some small areas that have good soil and favorable climate are isolated by so many nearly impassable mountain ranges that they are not thickly settled or carefully tilled. Such areas are found on the heights of the Massif de la Selle and the Massif de la Hotte. Many other areas, especially places on the mountain sides, are so steep, rocky, and unapproachable that they are left in forest and serve only as pasture for cattle, goats, and hogs. Good examples are the rugged slopes of the Morne du Cap and of the Montagnes Noires.

In both mountain and plain the climate, especially the rainfall, greatly influences the productivity of the land. Large areas that stand in the lee of mountain ranges and that are thus cut off from the life-giving east or northeast rains are arid and sterile. Without irrigation they can support only a scanty population. Among these barren areas are the Arbre Plain, the lower part of the Artibonite Plain, much of the Central Plain, and many small plains of the south coast. The upper part of the Artibonite Plain, the Arcahaie Plain, the Cul-de-Sac Plain, and other areas are saved only by irrigation. The lower southwest slopes of the high mountain ranges generally are not susceptible of reclamation.

Not the least essential requirement for successful agriculture is a good soil, for only where the soil is deep enough and fertile enough to produce crops year after year can a dense population be developed and maintained. The composition and texture of the soil is closely related to the areal

geology and is more fully discussed in Part II. The soils of the Republic may be classified briefly as alluvial soils, soils residual from limestone, and soils residual from igneous rock. The alluvial soils cover the surface of most of the larger plains and many similar but smaller valleys and plains. Although they constitute probably less than 30 per cent of the total area they support perhaps more than 50 per cent of its population. The greater productivity of these plains is due not entirely to the nature of their soil but in part to their smooth surface and their superior accessibility.

The limestone that covers so large a part of the Republic yields on weathering a red clayey soil which is very fertile and which for some crops is superior to the alluvial soils. Areas in which the surface is smooth enough to permit the retention and cultivation of this soil are well cultivated and thickly settled. Many small bodies of such land are scattered through the mountains, especially on the summits of the ranges. Examples are the Bombardopolis Plateau, the crest of the Chaîne des Mateux, the mountains of Dame-Marie and Jérémie, and the interior plateaus of Gonave Island.

The soils derived from igneous rocks are generally thin and poor and support only a scanty population. Some of the granitoid rocks of the northeastern part of the Republic, such as those at Vallière and the volcanic rocks of Plaisance and Terre-Neuve are an exception to the rule. These rocks yield a fairly deep and fertile soil, which with sufficient rainfall is highly productive, and the areas so favored are well settled.

AGRICULTURE.

General Features.

Agriculture has been the basic and dominant industry under both the colony and the Republic. About 80 per cent of the people (see p. 67) live in the rural districts and get their living from the soil. In this description the leading agricultural and live-stock products are divided into two distinct classes—those grown for export and those grown for local consumption. The first class includes coffee, cotton, cacao, sugar, honey, and hides and skins. The second class includes live stock and a great number of grains, vegetables, and fruits. As any discussion of the present state of agriculture inevitably leads to comparisons with that in the French colony, which was in its day the most productive and prosperous region in the New World, a brief review of the state of agriculture in colonial times is given with the description of its present state. Most of the information regarding colonial agriculture other than statistics of exports is taken from the work of Moreau de Saint-Méry, to which reference will be made by volume and page wherever direct credit seems to be necessary.

Chief Export Crops of the Colony and of the Republic.

TOBACCO AND INDIGO.

Tobacco and indigo, two crops that are no longer of great value, occupied a prominent place among the colonial exports. Tobacco, the crop first grown, was cultivated by the buccaneers on Tortue Island.[1] It was the leading crop until the cultivation of indigo was begun. According to Moreau de Saint-Méry,[2] the colony owed its first real prosperity to indigo. Although wild indigo (indigo marron) grows in the Republic, the introduced variety (indigo franc) seems to have been preferred wherever it would grow. In certain soils, however, only the wild indigo would thrive. In the early part of the eighteenth century indigo was the leading export crop, but later it yielded its rank in turn to sugar, coffee, and cotton, and at the end of the colonial period it occupied the fourth place. It was still the leading crop in a few areas, such as Jean Rabel and parts of the Artibonite Plain, where the land was too low, hot, and dry for coffee and could not be irrigated to raise sugar cane. The quantity of indigo and the leading ports from which it was exported in 1791 are shown in the table on page 78. More than a third of the total was produced in St.-Marc, although Cap-Haïtien, Port-au-Prince, and Les Cayes exported considerable quantities. Probably this supply was drawn from a much larger area than that immediately around the smaller ports, which owing to their commanding situations, were the principal ports of major divisions of the colony. One of the chief disadvantages of the culture of indigo seems to have been that it impoverished the soil rapidly and ceased to flourish. Its cultivation has been abandoned since colonial days, and the general use of synthetic indigo will probably prevent any considerable revival. Tobacco culture was dead at the end of the colonial days, and although the plant seems to succeed well, all later attempts to revive its cultivation have been short-lived, and the Republic now imports nearly all the tobacco it consumes.

SUGAR.

Sugar cane was introduced into Spanish Santo Domingo soon after the island was discovered, but it appears to have been first cultivated in the French colony on the Léogane Plain in 1680.[3] It proved to be the most lucrative crop of the colony, and its cultivation spread rapidly to all areas where the conditions were at all favorable for it. The most famous plantations of the colony were in the North Plain, especially near Limonade and Quartier Morin and in the near-by valley of Limbé. Water

[1] Labat, Voyage du Père Labat aux Isles de l'Amérique, vol. 5, pp. 63-64, La Haye, 1724.

[2] Idem, vol. 1, p. 24.

[3] Idem, vol. 2, p. 450.

power was used extensively to turn the cane mills, but irrigation seems to have been relatively little practiced, as the natural rainfall generally sufficed to produce good crops. In the west and south, however, on the Artibonite Plain, Cul-de-Sac Plain, and even the Cayes Plain, irrigation generally was imperative. It was for the extension of sugar culture in these areas that the French built the remarkable systems of irrigation works that still form the basis of the irrigation that is now practiced in the Republic. These works are more fully described in Part V.

The necessity for thorough tilling and preparation of the land and generally for irrigation also, as well as for a high temperature, has always restricted the raising of sugar cane to the alluvial plains and valleys, where the land is fairly smooth and free from stones. It was on the four larger plains—North Plain, Cul-de-Sac Plain, Léogane Plain and Artibonite Plain—that the great bulk of colonial sugar was raised, and it is on these and the Central Plain that any large modern sugar industry must be developed. Nevertheless the industry in colonial days extended to nearly every small alluvial plain or narrow valley where the conditions were favorable or could be adapted to the growth of sugar cane. On the Léogane Plain long-continued cropping is said to have depleted the soil so much that fertilization was necessary.[1]

Sugar refining was highly developed in colonial days, and nearly half the quantity exported in 1791 was refined. The table on page 78 shows that the value of the sugar exported was more than 50 per cent of the value of total exports in 1791. Political as well as geographical conditions made Port-au-Prince, Cap-Haïtien, and Les Cayes the leading ports. Normally Cap-Haïtien probably surpassed Port-au-Prince, but its exports in 1791 were greatly curtailed by revolutionary disturbances.

Sugar cane has always been grown to supply the domestic demand. Unrefined brown sugar (rapadou), is an article of food, and raw sugar cane is highly prized. A considerable quantity of sugar cane is used in making liquors, particularly rum. Plate VII, *A* shows a small cane mill of the type that is common throughout the Republic. Since 1915 an effort has been made to develop the sugar industry on a large scale, and an American company has established a big plant at Port-au-Prince and laid out extensive plantations on the Cul-de-Sac Plain. The sugar exported in 1921 and 1922 (see table, p. 79) was principally the output of this company.

COFFEE.

Coffee was introduced from Martinique by the Jesuits[2] and was first grown successfully at Dondon, where the first establishment for its preparation was installed in 1738. Its culture spread with amazing rapidity,

[1] Moreau de Saint-Méry, op. cit., vol. 2, p. 450.
[2] Idem, vol. 1, p. 164.

for it was found to be especially adapted to the mountainous regions, where sugar cane could not be raised and where indigo had given only desultory success. Forests were cut down everywhere and coffee plantations took their place. They were still being extended rapidly at the time of the Revolution. It was estimated in 1908 that the total area of coffee plantations in the Republic was more than 500 square kilometers.[1]

Coffee is grown successfully between latitudes 25° N. and 25° S. It thrives best between 300 and 1,500 meters above sea level, although under exceptional conditions it is grown commercially at lower altitudes. In the neighboring island of Porto Rico the best coffee is said to grow on soils derived from igneous rocks,[2] but although soils derived from igneous rocks produce excellent coffee in the Republic of Haiti they are probably no better adapted to its cultivation than some of the ocherous soils derived from limestone. Deep soil is necessary, for the plant has a long vertical tap root, but loose stones are not objectionable if the soil does not dry out too rapidly. Excellent plantations are found on steep and stony slopes. A fairly heavy rainfall is necessary, but some dry weather also is required. Deep, well-drained soils that support a good growth of natural forest are generally suitable for coffee. Some shade is required, and several kinds of forest trees are used to obtain it.[3]

Coffee generally grows better on north slopes, mainly, no doubt, because they receive more rain but partly, perhaps, because they are sheltered from the excessive heat of the sun. Nearly all the north slope of the Massif du Nord produced excellent coffee in colonial days, that of Le Borgne being especially famous. Coffee was the chief crop of the Montagnes Noires, of Grands-Bois, and of practically all the mountainous area of the Southern Peninsula. The coffee of Grands-Bois was perhaps the most famous in the colony.[4]

Coffee is cultivated now in much the same way that it was formerly. The plant grows virtually wild at many places. The chief producing areas are about the same as those of the colony. The coffee of St.-Marc is particularly esteemed in the French market. Plaisance and Petit-Goave are well-known producing areas.

The value of the coffee exported in 1791 constituted about one-fourth of the total value of the exports. In recent years the value of coffee has constituted about two-thirds of the total value of exports. The quantity exported annually varies greatly, as is shown by the following table:

[1] Internat. Bur. Am. Republics Bull., Dec., 1908, p. 1095.

[2] McClelland, T. B., Indicaciones acerca de la siembra de café en Puerto Rico, Estación Experimental Agrícola de Puerto Rico circ. No. 15, Mayagüez, Oct., 1914.

[3] Fauchère, A., Culture pratique du caféier et preparation du café, p. 28, Paris, 1908.

[4] Moreau de Saint-Méry, op. cit., vol. 2, p. 293.

Pounds of coffee exported annually in 1901–1905, 1909, and 1910.[1]

1901	56,372,192	1905	38,306,055
1902	64,950,274	1909	41,634,470
1903	51,446,193	1910	79,023,168
1904	81,617,568		

The Report of the Receiver of Customs for 1920 truly says that "coffee is the principal crop of Haiti, the staple on which her people in the main depend for existence, and the export tax thereon is the largest single source of revenue to the state."

COTTON.

Cotton is indigenous to the West Indies, and in the island of Haiti it grows as a perennial shrub, attaining a height of 3 to 5 meters. It grows wild but when desired for market is generally cultivated in a crude way. It thrives best if replanted every few years. The native plant seems to have supplied practically all the cotton exported by both the colony and the Republic. Moreau de Saint-Méry[2] records an attempt to introduce, at St.-Louis du Sud, an improved variety, which however, does not appear to have become extensively cultivated. The cotton plant requires some rain in the early period of its growth but will endure much drought later. It appears to grow best on calcareous soils and at low altitudes. It is the leading crop of certain lowland areas, such as the Arbre Plain, parts of the Artibonite Plain, and Cul-de-Sac Plain, where irrigation is impracticable and the climate is too hot and dry for coffee. In colonial days it was exported chiefly from St.-Marc and Port-au-Prince. (See table, p. 78.)

Cotton is now generally cultivated in about the same way and to the same extent as in colonial days. The quantity exported varies greatly, as the price fluctuates, depending upon the quantity picked rather than upon the quantity grown, which usually exceeds that marketed. When prices are high cotton is marketed in great quantities, but when prices are low it may nearly disappear from the market. An American company recently attempted to introduce cotton-growing on a large scale in the Central Plain. An improved American cotton was introduced, but it failed to mature properly during the first season, and further experiments have been checked temporarily by a great drop in price. Cotton raising, however, appears to offer much promise of success when its details have been thoroughly worked out. Similar difficulties were encountered and surmounted in introducing the cultivation of sea-island cotton into the British West Indies.[3]

[1] Figures from Rapports de la Chambre des Comptes, in Le Moniteur. For 1901-2 see No. 27, p. 205, 1905; for 1903 see No. 42, p. 327, 1905; for 1904-5 see combined No. 16 and 17, p. 101, 1910; and for 1909-10 see No. 34, p. 243, 1912.

[2] Op. cit., vol. 2, p. 648.

[3] See publications of Imperial Dept. Agriculture for the West Indies.

CACAO.

The cacao tree is another indigenous plant. Its value was recognized early in colonial days, but it never attained the importance of coffee. It ranked fifth, however, in the order of value of colonial exports in 1791, or sixth if syrup, a by-product of the sugar industry, is considered. The principal area of production in colonial days, as now, was the west end of the Southern Peninsula, in the communes of Dame-Marie and Jérémie. Here cacao in great measure takes the place of coffee, growing in large forests or orchards on the gentler slopes of the limestone mountains. Early in the colonial period St.-Michel de Fonds-des-Nègres was famous for its cacao.

Cacao grows between latitudes of 20° N. and 20° S., and thrives best at altitudes less than 800 meters above sea level, in deep, well-watered, but well-drained soil. It requires close shade and thorough protection from strong winds. Banana trees, rubber trees, bois immortelle, and other trees are used for shade and windbreaks. More rain is required for cacao than for coffee. These exacting conditions therefore restrict the range of the cacao tree considerably more than that of the coffee tree.[1]

HONEY.

Although honey is only a minor export, it appears regularly among the list of exports of the Republic. Bee culture was introduced in colonial days but does not seem to have attained much success. Now, however, it is a recognized industry, probably capable of considerable extension. Haitian honey is of excellent quality and probably could with little effort obtain a wider market.

Crops Grown for Domestic Consumption.

Many grains, vegetables, and fruits, both cultivated and wild, form a part of the dietary of the people but seldom find their way outside the country. The principal grains are corn (maïs), petit-mil, and rice (riz). Corn is cultivated successfully on the gentler mountain slopes up to altitudes of 900 to 1,200 meters where there is enough moisture. Also, although the climate is rather too hot, much of it is raised in some of the lowlands, especially the Artibonite Plain. The ears are small but good, the commonest corn being yellow. Most of the crop is ground into meal and used for food, although a little is fed to stock. The high prices offered in 1917, 1918, and 1919 caused the export of a considerable quantity, most of which went to Cuba,[2] but its export is very unusual. Ears of corn in the

[1] See article "Cacao" in International Bur. Am. Republics Bull., Sept., 1908, English section, pp. 471-482.

[2] See report of Consul John B. Terres of Port-au-Prince, in Supplement to Commerce Reports, Bureau of Foreign and Domestic Commerce, Washington, November 9, 1918.

A. SMALL MILL FOR CRUSHING SUGAR CANE.

B. METHOD OF DRYING CORN.

husk tied together and hung up in great bunches on trees or poles for protection from animals form a conspicuous feature of the corn-raising areas. (See Pl. VII, *B*.)

Petit-mil is one of the nonsaccharine sorghums, probably a variety of durra. It is raised extensively on the valleys and plains. The grain is used for food and the fodder is fed to stock. Considerable rice is raised locally, and more is imported to supply the great demand for the national dish—rice and beans. Beans and peas of several varieties are raised for domestic consumption. The Congo pea (pois congo) from Africa is one of the most esteemed varieties.

A very important food plant is manioc, commonly called cassava, from the roots of which cassava bread is made. In some localities it is the staple food. Yams and sweet potatoes (patate) are among the most widely cultivated and used vegetables. Of the fruits, perhaps the commonest are the plantain (banan), banana (figue banan), orange (orange), alligator pear (avocat), mango (mango), pineapple (anana), and coconut (coco). The plantain, picked green and cooked, forms a staple like bread at many places. Many less common fruits are highly prized in season, such as the grapefruit (shaddock), breadfruit (arbre-à-pain), grape (raisin), mulberry (mûre), cherry (cerise), apricot (abricot), corrosol, cayemite, and sapotille. Fruits of temperate climates can be raised on some of the high mountains. Blackberries (mures sauvages) and strawberries (fraises) grow at Furcy.

Nearly all these fruits and vegetables are raised in small gardens on little individual plots of land. They are characteristic of the mountains rather than of the plains, which are more often devoted to cotton, sugar cane, grains, and grass. Some localities are known throughout the Republic for the excellence of certain fruits or vegetables that they produce, and the local trade in these commodities is a rather large industry. No attempt has been made to standardize products, such as fruits, and raise a marketable article of uniformly superior quality. This neglect appears to be most unfortunate, for the country can produce oranges, bananas, pineapples, and other fruits that could compete successfully in any market with fruit raised elsewhere, and the geographical location of Haiti is more favorable than that of several fruit-growing countries of tropical America.

Live Stock and Poultry.

The live stock of the Republic includes mainly horses, mules, donkeys, cattle, goats, sheep, and hogs, all originally imported from Europe. They are raised entirely for local use, except that their hides and skins are exported. Stock raising is the principal industry in areas where the soil and climate are unsuited for intensive agriculture. The savannas of the North Plain, Central Plain, Artibonite Valley and Cayes Plain, and of certain mountain lands are devoted mainly to raising horses and cattle.

The horses, which are small but hardy, are used for riding and to a small extent for driving. Mules are used for riding and for packing heavy loads, as they are stronger and tougher than the horses. Donkeys, however, are the real burden bearers; nearly all the produce that is carried over the mountain trails is borne by them. Cattle are raised chiefly for meat and hides, rarely for milk. Oxen are used for drawing loads in the plains.

Short-haired goats of many colors are perhaps the commonest domestic animals. They are valued chiefly for their meat and skins, although they also yield most of the milk produced in the country. They are especially adapted to browsing rugged mountain sides that are unfit for cultivation and inaccessible to other pasture animals. Sheep are raised in only a few places. The wool is not of very good quality. Hogs are nearly as common as goats. They forage everywhere, living on seeds of trees and on fruits, vegetation, and waste. They are of a lean, rangy type, but their meat is highly esteemed.

Chickens, turkeys, and guineas are the commonest fowls and are raised nearly everywhere, both for eggs and meat. Wild guineas and wild pigeons are common at some places, particularly in the Central Plain.

All the domestic animals and the poultry could be greatly improved by careful breeding and selection.

Methods of Farming and Future of Agriculture.

As has already been intimated, the methods of farming are rather crude, nearly all the work being done by hand. Doubtless much of it must always be performed in this way, for much of the land is rough and stony and is divided into small plots. On the plains, however, traction plowing and cultivation has been introduced successfully in recent years and can be greatly extended. Any great increase in the production of export crops is inextricably bound up with the problem of conserving and distributing water for irrigation. (See Part V.) Much can be done also, however, by improving and standardizing farm products and fruits and by perfecting methods of marketing. These improvements are greatly to be desired, for agriculture is and undoubtedly must continue to be the country's mainstay and support.

COMMERCE.

General Features.

Foreign commerce has remained much the same under the Republic as it was in colonial days. The raw products of the plantation and forest constitute the great bulk of the exports; manufactured goods, particularly textiles and prepared foodstuffs, comprise the greater part of the imports. The value of the exports has generally exceeded that of the imports. These features are brought out in the following table, which gives the

official records of foreign trade for several years at different periods during and since colonial days. In recent years, however, the ratio of imports to exports has been unusually high.

Value in United States currency of imports, exports, and total foreign trade of the colony and of the Republic of Haiti at different periods.

Year.[a]	Imports.	Exports.	Total foreign trade.
1788 [b]	$20,590,572	.....	.....
1791 [b]	.....	$40,060,327	.....
1889 [c]	.....	.....	$26,188,569
1890 [c]	10,060,979	14,165,789	24,226,758
1891 [c]	8,823,776	14,340,234	23,164,010
1903 [d]	3,966,388	8,926,939	12,893,327
1913 [e]	9,876,555	17,285,485	28,499,075
1917 [f]	8,606,086	7,220,290	15,826,376
1918 [f]	10,180,693	6,276,321	16,457,014
1919 [f]	17,117,608	21,460,045	38,577,653
1920 [f]	27,398,411	18,990,032	46,388,443
1921 [f]	11,957,205	4,953,570	16,910,775
1922 [f]	12,350,271	10,712,210[g]	23,062,487

[a] The fiscal year under both the Republic and the colony has extended from October 1 to September 30, and this is the period covered. The figures for 1920, for instance, cover the period October 1, 1919, to September 30, 1920.

[b] From Edwards, Bryan, Historical survey of the French colony in the island of Santo Domingo, pp. 199, 206, London, 1797. Edwards compiled his data from colonial records during a protracted visit to Cap-Haïtien. The livre tournois is valued at $0.20.

[c] From Handbook of Haïti, Bureau of the American Republics, Bull. 62, pp. 76, 77, Washington, 1892.

[d] Le Moniteur, No. 42, p. 327, 1905.

[e] From International Encyclopedia, Article Haïti.

[f] Based on annual reports of Administration of Customs, Haitian Customs Receivership, Washington, D. C.

[g] See note at bottom of p. 79.

Exports.

PRINCIPAL ARTICLES OF COLONIAL EXPORT.

At the end of the colonial period the four great staple exports of the colony, named in the order of their importance, were sugar, coffee, cotton, and indigo. Forest products and hides and skins occupied a leading place among the minor articles of export. Tobacco was once a staple, and indigo was formerly the leading product, but these were forced to yield to sugar and coffee, the production of which had grown to overwhelming proportions. In colonial days sugar manufacture had been developed to a high degree, and almost half the quantity exported was refined.

The following table shows the export value of the four great staples during the year 1791 and the relative rank of the ports of origin. The figures for 1791 are said to be 25 to 30 per cent less than those for the few years immediately preceding on account of disturbances growing out of the Revolution. Ordinarily considerably more sugar was exported from Cap-Haïtien than from Port-au-Prince, and the poor showing of Cap-Haïtien is due to the early outbreak there of revolutionary movements.

Quantity in French pounds[a] and value in United States currency of exports of four leading products in 1791.[b]

Sugar.		Coffee.	
Port-au-Prince	61,441,142	Cap-Haïtien	29,367,382
Cap-Haïtien	45,482,041	Port-au-Prince	14,584,023
Les Cayes	23,360,052	St.-Marc	5,521,237
Fort-Liberté	10,249,158	Jérémie	4,453,331
St.-Marc	10,238,639	Jacmel	4,357,270
Léogane	9,181,520	Fort-Liberté	2,321,610
Port-de-Paix	1,298,300	Les Cayes	1,843,403
Petit-Goave	1,074,103	Port-de-Paix	1,829,754
Jérémie	496,249	Léogane	1,786,484
Tiburon	341,650	Petit-Goave	1,395,690
Môle St.-Nicolas	128,180	Tiburon	305,740
Jacmel	116,176	Môle St.-Nicolas	294,550
St.-Louis du Sud	11,600	St.-Louis du Sud	90,706
Total	163,405,220	Total	63,151,180
Approximate value in United States currency[c]	$23,432,470	Approximate value in United States currency[c]	$10,378,150

Cotton.		Indigo.	
St.-Marc	3,008,163	St.-Marc	357,530
Port-au-Prince	1,370,021	Cap-Haïtien	195,099
Les Cayes	720,770	Port-au-Prince	176,918
Jacmel	613,019	Les Cayes	105,456
Jérémie	189,194	Port-de-Paix	61,472
Léogane	154,084	Léogane	12,520
Other ports	230,875	Other ports	21,021
Total	6,286,126	Total	930,016
Approximate value in United States currency[c]	$3,514,450	Approximate value in United States currency[c]	$2,175,024

[a] To obtain equivalent values in pounds avoirdupois add about 8 per cent.

[b] Data recast from Edwards, Bryan, Historical survey of the French colony in the island of Santo Domingo, pp. 198, 199, London, 1797.

[c] Computed on basis $0.20 for the value of the livre turnois. The actual value was a trifle less.

TREND OF CHANGES IN EXPORTS.

For some time during and after the Revolution the exports decreased greatly, but they have gradually grown up again, though with some modifications, to something like their former volume. Coffee has replaced sugar as the leading staple exported. Sugar almost disappeared from the list of exports until very recent years, when an attempt was made to revive the industry. Naturally indigo has completely disappeared as an export. Cotton, though it has had many vicissitudes, has nearly retained its former standing. When prices are high it appears in great quantities; when they are low, its output shrinks to small proportions. Cacao has retained an important place; so also have dyewoods and lignum vitae, hides and skins, and generally honey. Other articles, like castor beans and corn, appear and disappear sporadically. In general coffee, cotton, forest

products, and hides and skins are staples. Their volume and relative value can be judged from the following tables:

Principal products exported from Haiti in 1921 and 1922.[a]

Material.	Oct. 1, 1920, to Sept. 30, 1921.	Oct. 1, 1921, to Sept. 30, 1922.
	French pounds.[b]	*French pounds.*[b]
Coffee (about 8 per cent is triage)	45,689,637	58,425,614
Cotton	3,987,430	8,567,058
Cotton seed	8,014,774	16,568,649
Cottonseed oil	611,012	212,714
Cacao	2,355,319	4,396,620
Logwood	74,893,411	59,960,376
Logwood extract	.....	1,280,596
Hides	40,729	26,951
Goat skins	207,340	184,937
Sugar	10,511,004	20,597,925
Honey	890,684	1,445,580
Lignum vitae	5,537,006	4,141,500
Castor beans	146,461	25,044
Corn	.....	372,632
Orange peel	226,060	563,249
Fertilizer	1,907,888	.....

[a] From report of Administration of Haitian Customs, Haitian Customs Receiverships, fiscal period ending Sept. 30, 1922.

[b] To convert into English pounds add 8 per cent.

Value in United States currency of products exported from Haiti, 1917 to 1922.[a]

Material.	Oct.1,1916, to Sept. 30, 1917.	Oct.1,1917, to Sept. 30, 1918.	Oct.1,1918, to Sept. 30, 1919.	Oct.1,1919, to Sept. 30, 1920.	Oct.1,1920, to Sept. 30, 1921.	Oct. 1, 1921, to Sept. 30, 1922.[b]
Coffee	$4,620,554	$3,147,282	$16,407,234	$11,007,296	$2,912,575	$7,487,312
Cotton (including cotton seed and cottonseed oil).	485,199	850,274	2,005,374	2,463,631	475,425	1,547,205
Logwood (including extract and roots)	780,768	319,364	640,149	2,868,411	744,311	506,953
Cacao	489,695	430,348	648,396	606,801	94,487	274,124
Sugar (raw)	2	69	506,960	897,197	457,166	537,475
Hides and skins	291,621	162,144	519,952	354,448	75,738	65,125
Honey	191,096	174,089	260,566	131,235	28,883	62,076
Castor beans	49,541	336,707	231,454	100,512	3,724	574
Lignum vitae	107,113	36,386	70,825	114,923	62,013	26,257
Sisal	14,322	15,552	36,406	25,490	116	535
Shells (tortoise)	1,562	657	20,326	28,809	7,621	13,810
Fertilizer	955	5,308	13,222	19,477	7,949	.....
Beeswax	23,436	10,942	17,573	5,614	2,814	977
Orange peel	.....	.....	3,414	25,019	7,411	20,130
Mahogany	13,800	11,274	4,436	15,289	7,120	586
Corn	53,517	681,390	12,417	.....	.....	5,560
Old copper	3,248	2,332	4,627	12,789	359	2,202
Iron ore	.....	.....	.....	1,800	.....	.....
All other articles	93,861	92,202	56,714	311,891	65,858	161,809
Total	$7,220,290	$6,276,321	$21,460,045	$18,990,032	$4,953,570	$10,712,210
Percentage shipped to U. S.	54.39	80.83	44.49	52.15	32.38	13.44

[a] Annual reports of Administration of Customs, Haitian Customs Receivership, Washington, D. C.

[b] Value of exports for 1922 include the export tax. Figures for previous years do not include the export tax. In 1922 the export tax was $2,015,598, of which $1,752,768 was on coffee.

Imports.

The imports at the present time probably do not differ greatly in general features from those of earlier or even colonial days. By far the largest single items are cotton cloth, flour, and soap. Recent years have seen a growing demand for machinery. The values of the materials imported during the last six fiscal years are shown in the following table:

Value in United States currency of products imported into Haiti, 1917 to 1922.[a]

Material.	Oct. 1, 1916, to Sept. 30, 1917.	Oct. 1, 1917, to Sept. 30, 1918.	Oct. 1, 1918, to Sept. 30, 1919.	Oct. 1, 1919, to Sept. 30, 1920.	Oct. 1, 1920, to Sept. 30, 1921.	Oct. 1, 1921, to Sept. 30, 1922.
Cloth and fiber products (about 90 per cent cotton cloth)	$2,876,617	$3,627,186	$5,252,192	$9,852,533	$2,272,493	$3,670,189
Foodstuffs (about 40 per cent flour)	2,540,958	1,694,332	5,964,606	8,607,240	3,654,480	3,849,591
Soap	494,263	926,836	839,780	972,924	615,530	639,014
Iron and steel manufactures	121,165	844,812	731,228	957,505	805,365	427,895
Tobacco	229,189	255,825	381,884	626,251	698,725	454,715
Petroleum products	175,410	282,960	397,915	454,576	327,477	315,675
Liquor, beer, and other beverages	167,614	142,384	129,213	505,107	285,402	251,016
Machinery (agricultural, automobiles, vehicles)	65,216	99,759	197,345	277,083	90,837	106,158
Lumber and manufactures (wood products)	151,841	205,960	186,062	341,657	169,231	181,873
Leather goods	108,924	159,267	94,976	290,176	126,772	120,310
Chemicals and drugs	88,960	53,562	107,063	236,766	157,969	155,022
Cement	46,765	71,267	82,546	149,833	103,345	56,701
All other products	1,539,164	1,816,544	2,752,798	4,126,760	2,649,579	2,122,112
Total	$8,606,086	$10,180,693	$17,117,608	$27,398,411	$11,957,205	$12,350,271
Percentage of imports from U. S.	86.39	92.48	93.12	83.12	79.82	83.87

[a] Annual reports of Administration of Customs, Haitian Customs Receivership, Washington, D. C.

Principal Countries Trading with the Republic of Haiti.

France has always consumed the greater part of the output of Haitian coffee. This feature and the inherited kinship of language and political thought have caused the Republic of Haiti to depend upon France for certain special classes of products, such as books and the more fashionable clothing materials and works of art. There is a small amount of trade with the surrounding West Indian Islands, dependent on transient local conditions. For instance, in 1917 and 1918 a large quantity of corn (maïze), which is seldom exported from the Republic, was shipped to the neighboring Republic of Cuba.

During the last century the commerce of the Republic with the United States grew gradually to large proportions, and during the World War, in 1917 and 1918, it was almost exclusively with the United States. Since then, however, there has been a gradual readjustment. The preceding

tables show that about 84 per cent of the imports in 1922 came from the United States and that about 13 per cent of the exports were sent to the United States.

MANUFACTURES.

The manufacturing industries are small and not complexly organized. Basketry, rope, and simple household articles, such as chairs and straw mats, are made by hand in large quantities for domestic use. Small wood-turning shops that produce chiefly curios for tourist trade are common. Small cabinet shops produce cabinet work of real excellence, especially in mahogany. A plant for the extraction of dye liquor from logwood was successfully operated at Grande-Rivière du Nord for a few years. It burned down but was rebuilt and is now in operation. One company manufactures cigarettes at Port-au-Prince. The capital also has the only considerable ice factory in the Republic, but ice is made at small plants in other cities. Plants for cleaning and preparing coffee for market, known as "usines à café," are common, and some of them are rather large. Considerable cotton is ginned in plants in several of the larger cities, and some cotton-seed oil is made. The largest of these plants is in St.-Marc. Crude plants for making unrefined brown sugar (see Pl. VII, *A*) are common but are of small capacity. The "Hasco" sugar mill, owned and operated by the Haytian-American Sugar Co. at Port-au-Prince, is a large and modern plant, which is said to be capable of grinding 250,000 tons of cane annually, but it has not yet been operated to its full capacity. Several small brick plants supply virtually all the domestic demand for bricks. (See pp. 503-507.) Most of the domestic supply of salt comes from several evaporating works. (See pp. 509-510.)

TRANSPORTATION.

As most of the area of the Republic is exceedingly mountainous inland transportation is very difficult. All the larger cities are on the coast, where the bulk of the freight can be handled by water. Throughout the periods of both the colony and the Republic the coastwise traffic and passenger service in small sailing vessels has been great. These small vessels bring in large quantities of goods to the larger cities for sale or export.

Highways and Trails.

In colonial days oxcarts and carriages were used on all the larger plains, where roads were easily made, but intercommunication was very difficult. After much trouble and labor a vehicle road from Cap-Haïtien to Port-au-Prince was opened in 1787, and vehicular traffic between Port-au-Prince and Les Cayes was virtually unknown.[1] All parts of the colony were reached by horseback, however. As early as 1700, according to Labat,[2] it was possible to travel from Cap-Français to Léogane by way of the Central Plain.

[1] Moreau de Saint-Méry, op. cit., vol. 1, pp. 104, 662, et seq.
[2] Labat, op. cit., vol. 5, pp. 134-135.

Since 1915 the roads have been improved as far as funds would permit, and at present (1923) there are 960 kilometers of highway under continuous maintenance and passable for vehicles, including automobiles, at nearly all seasons. During the height of the rainy season there are two regions, one in the Plain of St.-Michel and the other between Miragoâne and Aquin, where traffic is difficult because the soil is alluvial.

The improvements most needed on the highways are bridges. There are not more than six steel highway bridges in the country, and many of the small rivers become dangerous or impassable after rains. Ferries are used to cross some of the largest streams, but fords are generally used and traffic must wait until floods subside. Work has been started (1923) on bridges for the larger streams and construction has been begun on a road from Las Cahobas to Hinche and a road from Las Cahobas to Belladère, on the Dominican border. This road to the border will make it possible to travel from Port-au-Prince to Santo Domingo City by automobile in twelve hours, whereas it now takes three days by way of Cap-Haïtien, Ouanaminthe, and Santiago.

Innumerable horse trails and footpaths lead from the main roads to almost every nook and cranny of the mountains. Over these rough and difficult trails and paths an enormous amount of coffee, vegetables, and foodstuffs are carried to the markets on the backs of burros or on the heads of market women. Although more and better trunkline highways are needed on the plains to reach areas that are not now accessible to wheeled traffic, large quantities of the country's products will necessarily continue to be transported by primitive methods over unimproved trails.

The following table shows the distances between the principal towns along the main highways.

Distances between towns in Haiti, in kilometers.

Port-au-Prince—St.-Marc	98
St.-Marc—Gonaïves	74
Gonaïves—Ennery	29
Ennery—Plaisance	27
Plaisance—Limbé	21
Limbé—Cap-Haïtien	26
Port-au-Prince—Cap-Haïtien	275
Cap-Haïtien—Ouanaminthe	71
Port-au-Prince—Léogane	32
Léogane—Petit-Goave	39
Petit-Goave—Miragoâne	22
Miragoâne—Aquin	47
Aquin—Aux Cayes	61
Port-au-Prince—Aux Cayes	201
Port-au-Prince—Pont-Beudet	18
Pont-Beudet—Mirebalais	35
Mirebalais—Las Cahobas	29
Port-au-Prince—Las Cahobas	82

Railroads.

The Republic has 259.5 kilometers of narrow-gage railroads, which are operated in several disconnected units by two companies.

The following table shows the distance between the terminal stations of the different sectors:

Distances in kilometers between terminal stations of railroads.

Compagnie Nationale des Chemins de Fer d'Haïti:	
Port-au-Prince—St.-Marc	105
Gonaïves—Ennery	33
Cap-Haïtien—Bahon	39
	177
Compagnie des Chemins de Fer de la Plaine du Cul-de-Sac:	
Port-au-Prince—Maneville	42.7
Port-au-Prince—Léogane	34.5
Street railways in Port-au-Prince	5.3
	82.5

The Compagnie Nationale des Chemins de Fer d'Haïti hopes to combine its units into one line connecting Port-au-Prince and Cap-Haïtien by way of Mirebalais, Las Cahobas, Hinche, and Bahon. The railroads of the Republic are greatly hampered by the lack of large business or agricultural enterprises to furnish patronage and by the lack of any large volume of passenger traffic. Labor is so cheap that transportation by animals competes with transportation by rail.

Telegraph and Telephone Systems.

The telegraph and telephone systems of the Republic are operated by the Government. There are 39 telegraph offices which handle foreign as well as local messages. The city of Port-au-Prince has a modern automatic telephone exchange with a capacity for 300 subscribers, which is now being increased to 500. Small exchanges are maintained in several other cities. The volume of the telegraph and telephone business in the Republic has doubled during the last two years.

Part II. GEOLOGY.

By Wendell P. Woodring, John S. Brown, and Wilbur S. Burbank.

RECONNAISSANCE GEOLOGIC MAP.

The reconnaissance geologic map (Pl. I, in pocket) is accurate to the published scale only along the routes traversed during the reconnaissance shown on Plate III (p. 24). In compiling it the maps published by Mr. L. Gentil Tippenhauer (see bibliography, p. 603) have been freely used. Regions distant from the routes traversed were mapped principally by long-range observations supplemented by Tippenhauer's maps.

The base map was compiled by the Service des Levés Topographiques under the supervision of Mr. Glenn S. Smith, chief of the Division of West Indian Surveys of the Topographic Branch of the United States Geologic Survey. The delineation of almost the entire shore line, of the features near the shore line, and of the course of Rivière Artibonite from its mouth to Mirebalais is based on aerial photographs controlled by triangulation, work done under the direction of Mr. E. L. McNair, of the United States Geological Survey. The location of towns and other features in the interior is based on all available published and unpublished information supplemented by personal observations. The topographic surveys were suspended in the winter of 1921-22 from lack of funds.

SEDIMENTARY ROCKS.

By Wendell P. Woodring and John S. Brown.

PALEOZOIC (?) METAMORPHIC ROCKS.

Sedimentary rocks are exposed at the surface over fully four-fifths of the Republic. Their age ranges from probably Paleozoic to Recent.

Metamorphic rocks, probably of Paleozoic age, occur as float on the North Plain and on the Léogane Plain and are found in place on Tortue Island. Quartz schist and mica schist were found as float on the North Plain east of Limonade. Although no bedrock exposures of the schist were seen the fragments found presumably represent a metamorphic basement on which the old basaltic rocks lie. These schists are much more metamorphosed than any of the old volcanic rocks or Cretaceous sediments and are therefore considered Paleozoic or early Mesozoic.

A specimen of garnetiferous quartz-mica schist that was found as float on the plain a little east of Le Trou shows the highest degree of metamorphism seen in any rock collected in the Republic. This rock is greenish gray to dark gray, fine grained, and distinctly schistose. It is spotted

with pinkish to reddish-brown patches of garnet. In thin section the rock is seen to be composed essentially of quartz, chlorite, biotite, magnetite, and garnet. The quartz comprises about 70 to 75 per cent of the volume and has a characteristic mortar structure, produced by granulation of the borders of the grains. The chlorite and brown biotite comprise 15 to 20 per cent of the rock and together with the finely crushed quartz occupy the spaces between the larger grains of quartz. Considerable magnetite and some rounded patches of garnet are scattered through the rock. The garnet has a slight reddish tinge and apparently has replaced the chlorite, mica, and quartz between the larger grains of quartz. The rock may have been formed by the metamorphism of an impure sandstone. It shows evidence of intense dynamic and thermal metamorphism of a character not observed as the result of deformation caused by intrusions of igneous rock in Cretaceous and later times.

Exposures of these older rocks were found on Tortue Island beneath limestone that is probably of upper Oligocene age. There the metamorphic rocks consist principally of much sheared limestones that have been completely recrystallized and in some places partly replaced by chlorite, epidote, and quartz. The limestone is exposed in a sea cliff a short distance east of the landing at La Vallée, on the south coast. It is a hard bluish-gray rock and contains a network of seams of calcite. About 150 meters east of the landing greenish limestone containing chlorite and stringers of quartz crops out in a sea cliff. Bluish schistose limestone underlies this rock. The beds are contorted and wrinkled. The schistosity planes in general strike N. 80° W. and dip 20° NE. Similar rocks crop out in the huge amphitheater inland from La Vallée, where the cover of upper Oligocene limestone has been stripped by erosion, but along trails their exposures are weathered. Float of a granitic rock, which presumably intrudes the schistose limestone, was seen on the trail to Source Lavier. Schistose rocks were also seen northwest of Pointe des Oiseaux, where the trail from La Vallée descends to the coast. The schistose limestone resembles similar rock on the south slope of Samaná Peninsula, Dominican Republic.[1]

No exposures of schists considered to be older than Cretaceous were found in the southern part of the Republic, but float consisting of mica and quartz schists like those from the northern part of the Republic was seen on the western part of the Léogane Plain. This material probably comes from an unexplored part of the mountains south or southwest of the plain.

CRETACEOUS SYSTEM.

Rocks that can be positively identified from fossil evidence as Cretaceous are confined to the Upper Cretaceous series. They consist principally of limestone and were found in only a few small patches in the

[1] A geological reconnaissance of the Dominican Republic: Dominican Rep. Geol. Survey Mem., vol. 1, pp. 53, 83, 182-183, 1921.

arrondissements of Cap-Haïtien and Grande-Rivière du Nord. Detailed examination of the Republic doubtless would disclose other similar patches, but the area covered by such rocks is probably very small.

Rocks that are tentatively referred to the Lower Cretaceous system on stratigraphic, structural, or lithologic grounds underlie rather large areas, chiefly in the Massif du Nord. Lithologically most of these rocks in the northern part of the Republic are grouped under the term argillite, although at places they show wide variation from this type. Rocks in the southern part of the Republic that are considered of the same age on indefinite grounds generally consist of metamorphosed limestone. It is not at all certain that all these rocks called Lower Cretaceous are of the same age. All of them are older than Tertiary, but some may be even older than Cretaceous.

The Upper Cretaceous rocks probably rest uncomformably on the rocks of supposed Lower Cretaceous age, but the actual contact was not examined. They contain small pebbles of the older igneous rocks. The Lower Cretaceous rocks in the northern part of the Republic appear to have been deposited on a basement composed mainly of volcanic rocks, of which they contain recognizable pebbles at some places. The relations of the argillite and volcanic rocks are considered elsewhere. (See p. 273.)

The fossils show that the Upper Cretaceous rocks are marine. (See list, p. 98.) The lithology and the absence of marine fossils in much of the Lower Cretaceous series of the northern part of the Republic indicate that they are marginal deposits, laid down in part on flood plains. These rocks are nearly everywhere thinly and evenly bedded, and in many places they show mud cracks and contain fragments of lignite. Some impure limestones, calcareous sandstones, and argillites in this series contain small Foraminifera, indicating that they were deposited in shallow marine waters. Most if not all of the limestone of supposed Lower Cretaceous age in the southern part of the Republic is marine.

Both series of Cretaceous rocks doubtless were once much more extensive, but erosion prior to upper Eocene time removed the greater part of them. The solubility of the limestones facilitated their rapid removal. The argillite, even though now in some places much indurated, is not ordinarily very hard and generally remains only where it has been preserved in the troughs of faulted or folded areas.

Detailed descriptions of the Cretaceous rocks as observed at different localities are given below.

Lower Cretaceous Series.

Description by regions.

Massif du Nord.

Plaisance Valley.—That part of the valley of Les Trois Rivières above Pilate is known as Plaisance Valley. All this rolling valley between the bordering mountains seems to be underlain by argillite. On the north bank

of Les Trois Rivières at the bridge near Plaisance an excellent exposure shows a thickness of about 40 meters of beds that strike north and dip 40° E. The beds are 2 to 5 centimeters in thickness and very regular. They consist of indurated dark-brown fine-grained sandstone or sandy slaty shale. Many of the weathered blocks contain peculiar ridges that suggest fossils, but that are apparently fillings of mud cracks.

About 300 meters southwest of the bridge on the road to Ennery brown to gray beds resembling those just described but more clayey and containing no visible sand grains are exposed in a roadside cut. An analysis of a sample of material from this exposure is given on page 502, under the discussion of possible raw materials for cement. Silica in the moisture-free sample forms about 56 per cent and calcium and magnesium carbonates only about 17 per cent of the total.

A number of other exposures of this series are found along the road farther southeast. The rocks differ chiefly in color, which varies from ashy gray to deep purple. At all the exposures the beds are steeply tilted.

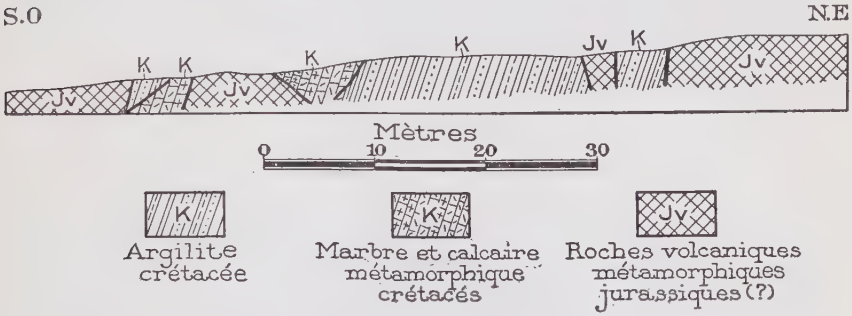


FIGURE 4.—Generalized section showing fault zone at contact of argillite and volcanic rocks as exposed in roadside ditch at Plaisance.

Rather different rocks, probably of the same series, are exposed at the foot of Mont Puilboreau in a roadside cut about 100 meters long. The thickness of beds exposed is apparently 60 to 75 meters. The beds dip steeply to the southwest, into the mountain. They consist in part of dark-gray metamorphosed cherty limestone, which is partly crystalline. Interbedded with the limestone is at least an equal amount of shale, indurated and at places slaty and showing ridges due to hardened fillings of mud cracks. The contact of these rocks with the igneous rocks to the south is probably marked by a fault.

At the north side of Plaisance Valley, just at the north edge of the town of Plaisance, the contact of the rocks of the valley with the volcanic rocks of Plaisance Mountain is well exposed in a ditch beside the road. The rocks exposed are purple argillite, metamorphic cherty limestone (which is partly changed to marble and which ranges in color from brown to white), and reddish volcanic rock. The three rocks are intermixed along a zone of step faults as shown in Figure 4.

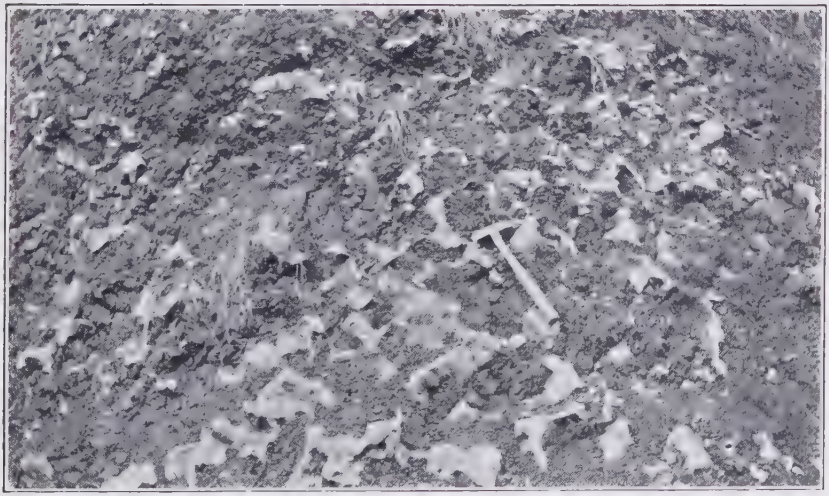
Similar argillite and other clastic rocks are exposed in the Plaisance Valley between Plaisance and Pilate. They consist principally of dark chocolate-brown thin-bedded argillite and thicker beds of harder sandstone. The argillite breaks into small blocks that have conchoidal surfaces. The general strike of these beds is northwest and they dip to the northeast and southwest at various angles.

Les Trois Rivières between Gros-Morne and Pilate.—Farther west the same series of rocks is exposed on Les Trois Rivières along the trail from Gros-Morne to Pilate. They crop out on both banks of the river above the second crossing toward Pilate. Their outcrop is a narrow northwestward-trending band between volcanic rocks on the west and middle Eocene limestone (Plaisance limestone) on the east. At this place the rocks consist of dark thin-bedded calcareous argillite. About 200 meters above the second crossing, on the right bank, a bed of limestone changed to white marble containing greenish streaks is interbedded with the argillite. At most of the exposures the beds strike northwestward and dip steeply southwestward. An exposure on the left bank about 1 kilometer above the second crossing shows that the beds are crumpled. (See Pl. VIII, *A*.) The contacts with both the volcanic rocks and the limestone are probably along faults.

Near Dondon.—Argillite and other rocks of the same series probably underlie nearly all the mountain-walled valley at Dondon, but over most of its area they are covered by alluvium. Good exposures are found in the trail between Dondon and Grande-Rivière du Nord at the north end of the valley, about 3 kilometers north of Dondon. The rock consists partly of brown or purple calcareous argillite and partly of similar but whiter rock, in fairly thin beds. Interbedded in the fine-grained argillite are one or two conglomeratic beds, about half a meter thick, which contain cobbles of igneous rock, some as much as 25 centimeters in diameter. The matrix of these beds consists in part of angular fragments of dacitic lava, quartz, and plagioclase in a calcareous cement containing a few small undetermined Foraminifera. Smaller lenses of sandy material not more than a few centimeters in thickness contain angular fragments of plagioclase, quartz, and volcanic rocks in an impure calcareous matrix containing numerous small undetermined Foraminifera.

Between this place and Carrefour Ménard, the nearest station on the railway between Cap-Haïtien and Grande-Rivière du Nord, there are numerous exposures of the argillite along the trail that follows a deep ravine leading down to the Grande Rivière du Nord. Most of the rock is thin-bedded fine-grained brown sandstone, which contains abundant fragments of lignitized wood. Some of the rock grades into impure limestone, which is brown and partly recrystallized. At some places it is a coarse conglomerate, composed of fragments of the underlying igneous rocks that are exposed at some places in the ravine. The rock everywhere is complexly folded and has been considerably metamorphosed.

A. CRETACEOUS (?) CALCAREOUS ARGILLITE ON LES TROIS RIVIÈRES BETWEEN GROS-MORNE AND PILATE.



B. PILLOW LAVA AND LIMESTONE OF SUPPOSED UPPER CRETACEOUS AGE ON THE NORTH SIDE OF THE ASILE VALLEY.

Northwest of this locality, on the trail leading from Milot to Christophe's Citadelle, on the northeast slope of the ridge called Bonnet-à-l'Evêque, exposures of purple argillite are common between altitudes of 300 and 650 meters above sea level. The rock is intricately folded and at places has a slaty cleavage.

Near Cerca-la-Source.—The largest area of Lower Cretaceous argillite is in the eastern part of the Massif du Nord, embracing the southern part of the arrondissement of Vallière. This area is probably continuous under the cover of Tertiary limestones with the area near Dondon and with that in Plaisance Valley. Near the Dominican border the area covered by these rocks is about 11 kilometers wide, but the width is less toward the northwest. Its length is about 60 kilometers.

These rocks are well exposed in bluffs on the right bank of Rivière l'Océan 100 meters below the crossing of the trail from Thomassique to Cerca-la-Source. At this place they consist of thin-bedded variegated argillite and thicker beds of greenish sandy material. The colors of the argillite are somber shades of chocolate-brown, olive-green, purple and brick-red. The argillite weathers into small blocks that have conchoidal surfaces. In the bluffs the beds have slumped, but ledges in the stream show that they strike northwestward and dip 40°–80° NE. or SW. or even stand vertically.

The greenish sandy beds consist of angular to subangular grains and crystals of plagioclase, grains of quartz, and flakes of brown mica. Grains of magnetite, a few prisms of apatite, and a very few grains of epidote and zircon are present. The brown mica is partly altered to greenish micaceous and chloritic material, which has partly replaced the plagioclase and quartz, giving the sandstone its greenish color and acting as a cement. The plagioclase is also partly replaced by calcite, sericite, or brownish products of the alteration of the mica. There is abundant calcite in the rock, but owing to alteration and recrystallization it is impossible to determine whether this mineral was an original constituent of the sandstone.

The brown shaly rock carries small fragments of plagioclase and quartz in a matrix of finer material containing an iron-stained calcareous and chloritic cement. The shale contains thin seams of coarser gritty material.

The argillite lies at the surface northeastward from Cerca-la-Source to the foot of the north slope of the ridge south of Lamielle, where the underlying pyroxene andesite crops out. The soil formed by the argillite is very thin, and the rock is well exposed at many places along the trail. On weathered surfaces it is dark brown or dark gray, and contains angular to subangular fragments of quartz and a few fragments of altered plagioclase, as well as flakes of white mica and grains of magnetite. The cement is largely calcareous, but there is considerable secondary chloritic material. Beds of gray calcareous sandstone, which weather brownish, contain angular to subangular fragments of quartz, a few fragments of

plagioclase largely altered to sericite or kaolinite, and a few grains of magnetite. The grains are embedded in a calcareous matrix, which constitutes a large part of the rock.

Some of the rock has an incipient cleavage almost at right angles to the bedding. The beds undoubtedly are intricately crumpled, as in the shallow exposures along the trail they dip northeastward and southwestward at steep angles, the direction of dip changing within short distances. On the south slope of the first ridge northeast of Cerca-la-Source a network of branching quartz veins about 10 meters wide cuts the argillite. The white quartz débris from the veins makes a conspicuous band that is visible on the next two spurs to the northwest. In this distance the veins are offset twice by faults.

Morne du Cap.—In the Morne du Cap near Cap-Haïtien there are numerous small patches of a formation which, although rather different from anything else in the Republic, apparently should be classed with the Lower Cretaceous rocks. This formation consists mainly of very dark chert and of brown or yellow indurated mudstone and siltstone, considerably more metamorphosed than the Eocene rocks. Moreover, it is overlain unconformably by upper Eocene limestone. It probably rests unconformably on a basement of igneous rocks that are mainly of volcanic origin. This formation in its relation to the water supply of Cap-Haïtien is described on page 581.

The formation is typically developed at the shore and in bluffy slopes just above the shore near Carenage, the most northerly section of the city, and on Morne Calvaire, perhaps 200 meters to the southwest. It consists partly of brown or yellow siltstone, claystone, or fine sandstone, partly of dense black or blue chert, all in generally rather thin beds that average perhaps 8 to 15 centimeters in thickness. The chert at some places forms solid beds or constitutes a whole series of beds several meters in thickness, but at other places it forms nodules or concretionary masses. The claystones at places appear to grade into very impure limestone. The whole formation is much shattered and breaks into minute polygonal blocks, which at many places form a talus over weathered slopes. Such material is successfully used as top dressing for roads in the city. (See p. 497.)

Thin sections show that some of the chert probably is in part of radiolarian origin, as Radiolaria can be recognized. It also contains some Foraminifera, but the rock is so greatly metamorphosed that the proportion of the two kinds of organisms is not easily determinable. In many features the rock resembles some of the Franciscan chert of California.

Beds of coarser, distinctly detrital material and even of coarse conglomerate appear at places, the conglomerate probably being near the base of the formation. At Carenage the bluffs of blue chert above the shore are underlain by sandstone and conglomerate, which crop out on

the beach. This conglomeratic material contains much-weathered fragments of dark igneous rocks and also rounded masses of chert, apparently concretionary. Farther northeast the conglomerate appears to be underlain by much-weathered greenish volcanic rock. The following section was measured in a ravine about 200 meters north of the end of the street in Carenage. The beds strike N. 10° E. and dip 30° NW.

Section of Lower Cretaceous beds near Cap-Haïtien.

	Meters.
Thin beds of yellowish sandstone and interbedded chert	41
Same as above, but thicker beds, cherty nodules	36
Thick beds of blue chert	8
Soft gray sandstone containing a bed of blue chert about 25 centimeters thick	5
Greenish weathered igneous rock	2
Beach.	
Thickness of Cretaceous beds exposed	92

On either side of the east gate to Morne Calvaire there is a bluff, 5 to 10 meters in height and nearly 100 meters in total length, in which the formation is well exposed. The rocks are chiefly cherty beds and brown siltstone. The siltstone has blue-black or brown iron stains on fractured surfaces. In this exposure there is one peculiar bed about 2.5 meters thick, apparently a fine conglomerate composed mainly of fragments of greenish igneous rock but partly of small pebbles of chert resembling the underlying cherts. However, the conglomerate appears to be perfectly interbedded in the series, and whether it denotes an unconformity is doubtful. Other exposures of a similar bed of conglomerate were noted at several places in the Ravine de la Belle Hôtesse.

Many other small exposures of the formation were noted, particularly around the shore of the cape north and west of Cap-Haïtien. Those near the town are shown in some detail in Figure 37 (p. 579) in connection with the description of the water supply.

The structure of the formation is complex. Everywhere it is sharply folded, and in good exposures many faults are visible. In the bluff east of Morne Calvaire the beds dip into the hill, but at the north end of the bluff there is part of a small anticlinal fold, much resembling a fan, in which minor faults are seen. Just south of the steps leading up to the gate there is a normal fault, which shows an offset of about a meter in the thick bed of conglomerate described above. A nearly vertical normal fault is exposed near the gate south of the city on the road to Port-au-Prince, where road metal has been dug off the hillside. The contact of the cherty formation with the porphyritic igneous rock is marked by a fault, which has an apparent displacement of at least 20 or 30 meters.

Montagnes Noires.

About 4 kilometers southwest of St.-Michel de l'Atalaye, on the trail through Section Paul to Dessalines, stretches a broad interior valley called Savane la Cidra, which lies back of the first range of the Montagnes Noires at the border of the Central Plain. This valley contains numerous exposures of a thin-bedded slaty argillite. The rock is gray or brown tinged at places with tints of blue or green. Part of the series consists of a black slaty limestone, which contains small undetermined Foraminifera. This rock weathers yellowish white. The beds are considerably folded.

In contact with this argillite appears a gray or green altered hornblende andesite. Both the argillite and the andesite have been metamorphosed by an intrusion of dacite porphyry. The argillite is partly replaced by epidote, chlorite, and quartz and contains cubes of pyrite.

Southern Peninsula.

Rocks of doubtful age that are known to be older than the oldest Tertiary rocks were examined at several localities in the Southern Peninsula. They are tentatively classed with the rocks of supposed Lower Cretaceous age in the northern part of the Republic.

Arrondissement of Jacmel.—In the area of basalt north of Jacmel there are several exposures of schistose limestones which apparently have been engulfed by the basaltic eruptions. An exposure of this limestone was found north of Coteaux on the trail from Jacmel to Léogane, about 500 meters north of the southern boundary of the basalt. The limestone is brown and dense and is much sheared but contains eyes of uncrushed limestone. In thin section the limestone is seen to be only partly recrystallized and contains small undetermined Foraminifera. The schistosity strikes N. 60° W. and dips 80° S.

Another thin zone of metamorphic limestone was seen just south of Corail-Brache on the same trail.

North of the divide along Ravine la Rououne, the western branch of the Rivière des Citronniers, there are exposures of light-brownish much sheared metamorphic limestone. The beds strike N. 80° W. and dip 50° S.

These metamorphic limestones appear to be overlain by the basalts, although the contacts generally were concealed.

Near Petit-Goave.—About 4 kilometers southeast of Petit-Goave, on a trail leading up the mountain slope, there are large exposures of a gray to grayish-brown impure metamorphic limestone, but the extent of the beds was not determined. The rock is in regular and rather thin beds, and some beds have a conchoidal fracture. The grayish-brown limestone contains *Globigerina, Textularia,* and other small Foraminifera. It probably is overlain by upper Eocene limestone, but the contact was not seen.

Arrondissement of Aquin.—About 2 kilometers west of the little village and chapel of Changier, at the highest point on the trail between

l'Asile and Cavaillon, some small exposures of a reddish schistose limestone were noted. The area covered is small, and the relations of this rock to the surrounding rocks are not known, but it is undoubtedly older than the prevailing upper Eocene limestone and is tentatively referred to the Cretaceous. Such highly metamorphosed sediments are not common in the Cretaceous but probably form local masses in less metamorphosed rock, as at Camp Perrin.

Arrondissement of Cayes.—Rocks which on rather indefinite grounds are tentatively assigned to the Lower Cretaceous were found at a number of other places in the Southern Peninsula. The principal area is north of the lowland near Camp Perrin, which is underlain by the lignite-bearing Miocene beds described on pages 236, 483. Here the rock is a thin-bedded, very cherty, generally chocolate-brown limestone, but some beds are whiter. Some beds are recrystallized and contain many closely spaced fractures, which are filled with coarsely crystalline calcite. About 2 kilometers north of the diversion dam of Canal d'Avezac the limestone appears to contain large zones of schist, which is probably derived from impure limestone by metamorphism. The beds are crumpled into close folds, the strike changing greatly within a few meters, but the prevailing strike is approximately east. No fossils were found in this limestone, but the degree of metamorphism indicates that it is at least as old as Cretaceous. It was seen in place only along La Ravine du Sud, beginning at a locality about a kilometer north of the diversion dam. Float of a similar rock is very abundant in the lowland, indicating that it is extensive in the mountains to the north. Float of similar brown metamorphosed limestone, which was noted at Port-à-Piment and elsewhere along the south coast, possibly indicates an extensive area of such rocks in the unexplored interior of the Montagnes de la Hotte.

Arrondissement of Tiburon.—Somewhat similar brown limestone was found along the trail near the north coast of Tiburon Bay. Basalt seems to overlie the limestone, but this relation was not definitely established. If the limestone really underlies the basalt the limestone probably is Cretaceous; if not, it probably is a phase of the upper Eocene limestone, which appears to cap the high ranges north of Tiburon.

Upper Cretaceous Series.

DESCRIPTION BY REGIONS.

Massif du Nord.

Near the Citadelle of Christophe.—A good exposure of limestone of undoubted Upper Cretaceous age was found on the trail between Dondon and the Citadelle of Christophe, about half a kilometer south of the junction of the trail with a trail leading from Milot to the Citadelle. The locality is on the mountain side, approximately east of the Citadelle, at an altitude of about 600 meters above sea level. (See Fig. 29, p. 462.)

The extent of the exposure is undetermined, but probably it is not more than 100 to 300 meters in diameter. The rock consists of white limestone, apparently massive and partly broken down by solution into a mass of large boulders. In the calcareous matrix there are a few small fragments, probably of volcanic rock. The whole limestone mass is richly fossiliferous. It contains some undetermined Foraminifera, but the conspicuous fossils are large, mostly fragmentary rudistid mollusks. (See list, p. 98, stations 9880 and 9746.)[1] Some single specimens on weathered exposures are more than a meter in length, but it is difficult to extract them from the tough rock. The limestone is virtually a reef rock formed by these mollusks.

The relations of this limestone to the underlying rocks were not determined. Two exposures of a thick-bedded tilted conglomerate found near by probably should be referred to the upper Eocene basal conglomerate. (See p. 111.)

Near La Tannerie.—Upper Cretaceous limestone was found near the railway station called La Tannerie, a few kilometers north of Grande-Rivière du Nord, at the northern border of the mountains. The limestone at this place forms the first low mountain ridge bordering the North Plain. It is exposed just north of La Tannerie, in a railway cut about 75 meters long and 7 meters in maximum height. The rock at the south end of the exposure consists mainly of dark-blue metamorphosed limestone containing prominent veins of crystalline calcite. At the north end the limestone is mixed with a considerable amount of purple argillite and dark-brown sandstone, evidently belonging to the Lower Cretaceous series as developed near Dondon. (See p. 88.) The whole mass is intricately faulted and badly crushed, and the intermixture of argillite and limestone is probably due to the faulting.

On the ridge west of this cut the limestone is exposed for several hundred meters. It is rather thick-bedded, the beds ranging from 20 to 40 centimeters in thickness. The strike is somewhat south of west and the dip vertical or very steep to the north. The rock is brown on weathered surfaces and is etched and furrowed by peculiar ridges. The broken interior is dense and dark blue. The rock contains small scattered fragments of igneous rock. No fossils show on the interior, but weathered surfaces contain undetermined Foraminifera and numerous fragments of rudistids (see list, p. 98, station 9881), which appear to be indigenous to the calcareous matrix.

To the south the limestone is in contact with quartz porphyry. Near La Tannerie the contact is along a ravine and is covered by detrital material, but westward it rises up the northern slope leading down to the ravine and curves gradually southward. Although the relations were not definitely

[1] The numbers given designate stations at which collections were made by members of the U. S. Geological Survey. The collections are deposited in the U. S. National Museum.

determined the contact is believed to be marked by a fault. Along the contact there is a zone, 2 or 3 meters wide, of altered green igneous rock.

Directly east of La Tannerie, on the mountain slopes east of the Grande-Rivière du Nord, there are small outcrops that appear from a distance to be limestone, probably the same as that at La Tannerie.

Morne Grand-Gille.—Morne Grand-Gille is an isolated hill in the North Plain about 3 kilometers northeast of La Tannerie. It stands just north of the road connecting Milot and Limonade and just east of the Grande Rivière du Nord. This hill is capped by dark limestone. Float found along the road at the foot of the hill indicates that the rock is the same as that at La Tannerie. A collection of float fossils made here was lost.

Montagnes de Terre-Neuve.

At an altitude of about 800 meters above sea level, on the west slope of Morne Guimbi, float limestone containing small indeterminable gastropods and an *Anomia*-like bivalve was collected. This rock may be of Upper Cretaceous age, although at the same locality float containing upper Eocene Foraminifera (see list opposite p. 144, station 9816) was obtained.

Massif de la Selle.

In the southern part of the Republic impure limestone and tuffaceous rocks, apparently interbedded in basalt, are considered Upper Cretaceous, although the evidence is rather meager. Some of these rocks contain fresh tuffaceous material and also marine fossils. The volcanic material must either have been blown into the sea during eruptions or was quickly washed from the land surface during floods. Other thinly laminated rocks that contain no marine fossils probably were laid down on flood plains.

Such rocks were seen at many places in the basalt areas of the Massif de la Selle. In the western part of the Commune of Marigot, along the trail leading from the coast to Étang Bossier, a brownish-gray shaly limestone was found in the area of basalt at a locality about a kilometer south of the lake. It contains small pieces of thick shell that have the fine fibrous texture characteristic of *Inoceramus*. A dark impure limestone containing finely laminated bands crops out on the same trail about half a kilometer closer to the lake. This rock contains fish vertebrae and carbonized plant fragments.

Rocks of the same age were seen at several places in the large basalt area around Furcy. They consist of black laminated calcareous tuff, sandy tuff, and banded chert. The black laminated tuff contains scattered fresh angular fragments of augite and fragments and crystals of plagioclase. Thin seams in the tuff consist largely of crystals of plagioclase and fragments of augite. The matrix is calcareous and contains *Globigerina, Textularia,* and other small Foraminifera, some of which have been replaced by hematite. The matrix is stained brown by iron oxides and other impurities.

Similar rocks crop out on the south slope of the mountains along the trail from Jacmel to Carrefour. Dark banded calcareous tuff and impure limestone are exposed on Rivière Gosseline, at the south end of the basalt gorge between the locality marked by the contact with upper Eocene limestone and Carrefour Andral, where the trail leaves Rivière Gosseline and ascends Rivière Mabial. These rocks are crumpled at the place where the trail crosses from the right to the left side of the river. Along the same trail near the crest of the mountains, at an altitude of 1,050 meters above sea level, on the south slope, a bed of black tuffaceous limestone stands vertically in a cut along the trail.

Numerous exposures of dark shaly limestone or tuffs were seen in the area occupied by basalt along the trail from Corail-Brache to the head of the valley of Rivière des Citronniers, on the eastern route from Jacmel to the Léogane Plain. Most of the rock exposed appeared to be in thin beds interbedded in the basalts. As these exposures were near the center of the basalt band it is probable that they are in the lower part of the basalt series.

At all these localities the exposures of these rocks are very narrow across the strike, and the beds seem to lie between basalt. They have a remarkably uniform northwesterly strike, indicating that they belong to the same series as the basalt. They apparently lie near the base of this series. At all the exposures examined the beds dip steeply, usually to the southwest, indicating that the rocks are folded, although the folding is not apparent from exposures of the basalt.

Massif de la Hotte.

Limestone that is probably of Upper Cretaceous age was found near the Grande Rivière de Nippes north of the Asile Valley, along the trail between l'Asile and Anse-à-Veau. In this region the Grande Rivière de Nippes occupies a narrow gorge cut mainly in basalt. About 3 kilometers from l'Asile the river bends sharply eastward, and the trail also turns eastward along the north bank of the river. At this turn a ledge of brown limestone, apparently interbedded with the basalt, is exposed. It strikes about N. 75° W. and dips 35° NE.

Perhaps 300 meters east of the turn in the trail and river the trail parts from the river, ascends a steep mountain side, and crosses a divide in basalt at an altitude of about 300 meters above sea level. At an elevation of 50 meters south of the crest of this divide there is an exposure of brown limestone, which strikes east and dips 55° N. beneath basalt. The trail for several meters follows a sharp V-shaped ditch along the contact.

A little lower on the hillside an exposure shows basalt containing fragments of limestone of irregular size and shape. The limestone is dark gray and partly recrystallized. Plate VIII, *B*, a view of this exposure, shows that ellipsoidal masses of basalt fit into cusp-shaped edges of pieces of

limestone. The head of the hammer shown in the view rests on one of the ellipsoidal masses of basalt. These features suggest pillow structure and that the basalt flowed under water where calcareous muds were being deposited, the calcareous mud filling the open spaces between the pillows of basalt.

At all these exposures the limestone contains undetermined calcareous algae, and at the exposure near the crest of the hill it contains small indeterminable gastropods. It is of marine origin and apparently was laid down when the basalt was being poured out. The masses of limestone that are included in the basalt contain small fragments of igneous rock clouded with iron oxides.

In the level savanna south of the first range of mountains south of Anse-à-Veau, along the same trail, there is a small ledge of brownish-yellow limestone which protrudes through the basalt that floors the valley. The rock is entirely recrystallized. It may or may not be the same as the rocks described in the preceding paragraphs.

Another exposure of brownish-yellow limestone was found 5 or 6 kilometers east of Baradères on the trail to Anse-à-Veau. It is just east of the crest of the third ridge east of Baradères. Basalt appears to overlie the limestone, which is poorly exposed. The limestone contains the coral *Actinacis* ? (station 9639).

In the northern part of the arrondissement of Nippes there is probably much limestone overlain by or interbedded with basalt, but some of it may be older than Upper Cretaceous.

FOSSILS.

The only fossils of undoubted Upper Cretaceous age come from the limestone in the arrondissements of Cap-Haïtien and of Grande-Rivière du Nord. Rudistid mollusks form huge reefs in this rock at some localities, particularly on the mountain side east of the Citadelle of Christophe. They are similar to some of the peculiar rudistids described by Whitfield[1] from Jamaica. Similar mollusks have been found in the Dominican Republic, Cuba, and St. Croix, indicating that this fauna is characteristic of the Upper Cretaceous of the West Indies. Although the evidence is rather meager, Dr. T. W. Stanton, of the United States Geological Survey, who examined the collections from the Republic of Haiti, believes that the fauna indicates a rather late Upper Cretaceous age.

Stations—Upper Cretaceous.

9881 (B 300 F). Arrondissement of Cap-Haïtien, mountain slope just west of La Tannerie, a station on railroad from Cap-Haïtien to Grande-Rivière du Nord, about 10 kilometers northwest of Grande-Rivière du Nord. J. S. Brown, collector. March 11, 1921.

[1] Whitfield, R. P., Descriptions of species of Rudistae from the Cretaceous rocks of Jamaica, W. I., collected and presented by Mr. F. C. Nicholas: Am. Mus. Nat. Hist. Bull., vol. 9, pp. 185-196, pls. 6-22, 1897.

9880 (B 296 F). Arrondissement of Grande-Rivière du Nord, trail from Dondon to Citadelle of Christophe, about halfway up mountain, about 3 kilometers east of Citadelle and 10 kilometers north of Dondon; altitude, 620 meters above sea level. J. S. Brown, collector. March 8, 1921.

9746 (B 317 F). Arrondissement of Grande-Rivière du Nord, same locality as 9880. W. P. Woodring and J. S. Brown, collectors. March 21, 1921.

Upper Cretaceous fossils from limestone of Massif du Nord.[a]

Species.	Massif du Nord.		
	Cap-Haïtien.	Grande-Rivière.	
	9881	9880	9746
Undetermined coral	×	....	....
Mollusca:			
Pelecypoda:			
Radiolites nicholasi Whitfield	....	×	....
Radiolites sp. cf. R. cancellatus Whitfield	....	×	×
Radiolites sp.	×	....	....
Genus ?, Caprinidae	....	×	×

[a] In the lists of fossils the names in the first enclosed heading (for example, Massif du Nord) indicate geographic divisions; those in the second heading (for example, Cap-Haïtien) indicate arrondissements. The numbers at the heads of the columns are those of the stations in the preceding list.

Stations—probably Upper Cretaceous.

9663 (W 67 F). Arrondissement of Jacmel, trail from Cayes de Jacmel to Étang Bossier, about a kilometer south of Étang Bossier; altitude, 200 meters above sea level. W. P. Woodring, collector. November 2, 1920.

9639 (B 113 F). Arrondissement of Nippes, trail from Baradères to Anse-à-Veau, third ridge east of Baradères. J. S. Brown, collector. November 22, 1920.

Upper Cretaceous (?) fossils from arrondissements of Jacmel and Nippes.

	Station.
Coral:	
Actinacis ? sp.	9639
Mollusca:	
Pelecypoda:	
Inoceramus sp. indet.	9963

TERTIARY SYSTEM.

Sedimentary rocks of Tertiary age are the most extensive surface rocks in the Republic, covering probably three-quarters of its area. Middle and upper Eocene, middle and upper Oligocene, lower and middle Miocene, and Pliocene deposits were seen during the reconnaissance. Rocks of lower Eocene age have not yet been recognized anywhere in the West Indies proper. The deposits that are considered middle Eocene in this report are the first deposits of that age recognized in the West Indies proper

outside of Jamaica. Rocks of lower Oligocene age—that is, of the age of the lower part of the Vicksburg group of the southeastern United States—were not definitely recognized in the Republic, but some of the limestones that are tentatively considered upper Eocene may be lower Oligocene. None of the Miocene deposits appear to be as young as the upper Miocene Cerros de Sal formation of the Dominican Republic. The Tertiary deposits and their equivalents in the Dominican Republic and other regions near by are given in the table on pages 100 and 101.

The rocks of Eocene and Oligocene age, corresponding to the Nummulitic series of the Mediterranean region, consist almost exclusively of limestone, but the Miocene and Pliocene deposits consist principally of detrital rocks. The Eocene and Oligocene limestones form many of the mountains of the Republic and give rise to rugged surface features in which cliffs, caverns, and sink holes are conspicuous. The Miocene and Pliocene detrital rocks are almost entirely confined to the larger valleys and plains and underlie intricately dissected lowlands. The extensive distribution of the limestones and of the younger detrital rocks to which they have so largely contributed accounts for the high percentage of calcium carbonate in the rocks, soils, and waters of the Republic.

Eocene Series.

The Eocene is the most extensive series of rocks in the Republic, both in area covered and in thickness. By far the greater part of the series is of upper Eocene age, but rocks of middle Eocene age attain a remarkable thickness in the arrondissement of Plaisance. Both the middle and upper Eocene rocks are characteristically limestones.

MIDDLE EOCENE.

Plaisance Limestone.

Name.—The name Plaisance limestone was used by Vaughan[1] for the limestone on the northeast slope of Mont Puilboreau. When the Plaisance limestone was named it was supposed to be upper Eocene, but Woodring[2] has recently shown that it is middle Eocene.

Areal distribution.—The Plaisance limestone crops out in a northwestward-trending strip in the southern part of the arrondissement of Plaisance and adjoining parts of the arrondissements of Gonaïves and Marmelade. This area comprises the crest and the upper part of the northeast slope of Mont Puilboreau and its prolongation northwestward and southeastward. The limestone was recognized as far to the northwest as La Pierre, on Les Trois Rivières, in the western part of the arrondissement of

[1] A geological reconnaissance of the Dominican Republic: Dominican Rep. Geol. Survey Mem., vol. 1, pp. 58, 94, 1921.

[2] Woodring, W. P., Washington Acad. Sci. Jour., vol. 12, pp. 244-247, 1922.

Tertiary sedimentary deposits of the Republic of Haiti.

American time subdivision.		Republic of Haiti.		Dominican Republic.		Localities of some other American equivalents.	European time subdivision.
Pliocene.		Hinche formation (non-marine). Conglomerates and marl near Jacmel.		Las Matas formation (non-marine.)		Panama, Jamaica, Cuba, and Costa Rica.	Astian. Plaisancian.
Miocene.	Upper.			Cerros de Sal formation.		Yorktown and Duplin formations, Virginia and North Carolina.	Tortonian.
	Middle.	Conglomerate, sandstone, and limestone along south edge of the Cul-de-Sac Plain.		Yaque group.	Mao clay. Mao Adentro limestone. Gurabo formation.	La Cruz marl, Cuba; Bowden marl, Jamaica; Gatun formation, Panama and Costa Rica; Porto Rico; Calvert, Choptank, and St. Marys formations, Maryland and Virginia.	Helvetian.
	Lower.	Artibonite group.	Las Cahobas formation.		Cercado formation.	Porto Rico; Shoal River marl and Oak Grove sand members of Alum Bluff formation, Florida.	Burdigalian.
			Thomonde formation and Maïssade tongue.		Baitoa formation.[a]	Uscari formation, Panama; eastern Porto Rico; Chipola marl member of Alum Bluff formation, Florida.	
			Madame Joie formation.		Bulla conglomerate.[a]		

Oligocene.	Upper.	Limestone around border of the Central Plain and elsewhere.	Cevicos limestone. Limestone east of Baní and elsewhere.	Anguilla; St. Croix; Porto Rico; Cuba; Panama; Tampa, Florida. Byram calcareous marl,[c] Mississippi.	Aquitanian. Chattian.
	Middle.	Limestone in Montagnes Noires, Chaîne des Matheux, and elsewhere.	Tabera formation.[b] Limestone near Túbano.	Antigua; St. Croix; Porto Rico; Cuba; Panama; eastern Mexico; Glendon formation, Gulf States.[c]	Rupelian.
	Lower.	(?) Limestone near Dondon and in the Chaîne des Mateux.		Red Bluff clay, Alabama and Mississippi; Marianna limestone, Gulf States.	Lattorfian.
Eocene.	Upper.	Limestone in all the mountain ranges.	Limestone at Damajagua, in the Sierra de Neiba, Sierra de Bahoruco and elsewhere.	St. Bartholomew; Cuba; Trinidad; Ocala limestone, and Jackson formation, Gulf States.	Priabonian.
	Middle.	Plaisance limestone.		"Yellow limestone," Jamaica; Claiborne group, Gulf States.	Auversian. Lutetian.
	Lower.			Trinidad; Midway and Wilcox groups, Gulf States.	Ypresian. Sparnacian. Thanetian. Montian.

[a] Largely contemporaneous.
[b] May include lower Oligocene.
[c] See Cooke, C. W., The correlation of the Vicksburg group; U. S. Geol. Survey Prof. Paper 133, 1923.

Gonaïves, and as far to the southeast as a locality in the arrondissement of Marmelade 3 to 5 kilometers northwest of St.-Michel de l'Atalaye. It probably extends farther northwestward in the arrondissement of Gonaïves. It is the limestone called "gelbe Kalke" by Tippenhauer.[1]

In the eastern part of the Montagnes de Terre-Neuve there is a conglomerate several hundred meters thick between the old lavas and the upper Eocene limestone. Several collections of fossils (see lists, p. 107, stations 9892, 9893, and 9894) indicate that the lower part of this conglomerate may be of middle Eocene age, but the fossils were collected from float, and the stratigraphic relations of the beds from which they were derived are not known.

The exposures on the northeast slope of Mont Puilboreau, along the road between Plaisance and Ennery, constitute the type locality.

Stratigraphic relations.—At its type locality the Plaisance limestone rests unconformably on volcanic rocks, probably of early or middle Mesozoic age, and has a thin but conspicuous conglomerate at its base. This basal conglomerate contains pebbles of the volcanic rocks and also of the argillites of supposed Lower Cretaceous age in the Plaisance Valley, although the contact between limestone and argillite was not seen.

Lithology.—At its type locality the Plaisance limestone consists almost entirely of hard limestone, usually gray, yellow, or white, and remarkably pure, as indicated by the analysis on page 501 of a sample that contained more than 99 per cent calcium carbonate ($CaCO_3$). Only the beds near the base are materially different. The basal beds consist of conglomerate, not particularly coarse, composed of rounded fragments of igneous rocks and argillite, interbedded with shaly material and with thin lenses of impure brownish-yellow limestone, which also contains detrital fragments. The proportion of limestone increases steadily above the base and there is a transition zone of considerable thickness between the conglomerate and the typical white or yellow limestone. In this transition zone the rock is chiefly yellow or buff limestone with some shale. The beds are 5 to 10 centimeters in thickness and the rock has peculiar knots or lumps, which give outcropping ledges in roadcuts a rough surface. The main mass of the limestone, above the transition beds, occurs in beds 10 to 25 centimeters in thickness, and on weathered surfaces it commonly appears massive. It is readily dissolved and generally pitted with large solution cavities. On weathering it yields a red clay soil. The fossils listed on page 107, stations 9771, 9857, 9888, 9889, 9858, 9441, 9859, 9860, 9442, 9861, and 9991, were collected on the north slope and crest of Mont Puilboreau.

At La Pierre, on Les Trois Rivières, the Plaisance limestone is brownish yellow, particularly on weathered surfaces, but some of the unweathered rock is dark gray. The fossils listed on page 107, stations 9753 and 9754, were collected at this locality.

[1] Tippenhauer, L. G., Petermanns Mitt., Band 45, pp. 153-155, pl. 10, 1899.

The conglomerate at the base of the Plaisance limestone is exposed in a roadcut on the east slope of Crête Salée, along the road from Ennery to St.-Michel de l'Atalaye. At this locality the conglomerate consists principally of pebbles of purple andesite and other igneous rocks embedded in a purplish calcareous matrix. Shaly beds near the base of the limestone are exposed along the west slope of Crête Salée along the same road. Limestone crops out higher on the west slope and on the crest. Weathered surfaces of this limestone have the peculiar lumpy appearance of the lower part of the Plaisance limestone at its type locality. The limestone seems to consist of calcareous lumps embedded in buff marl. Most of the corals, echinoids, and mollusks listed on page 107, stations 9792, 9952, 9950, and 9951, were found weathered out and lying on the surface in roadcuts or on dumps from roadcuts.

Thickness.—Only a rough estimate of the thickness of the Plaisance limestone is possible, as there are no accurate maps to show the width of the outcrop. The thickness seems to be at least 1,000 meters at the type locality, where there is no evidence of duplication by faulting.

Structure.—On the northeast slope of Mont Puilboreau the Plaisance limestone dips southwestward from 20° to 30°, and its strike parallels the trend of the crest of the mountain. The contact with the upper Eocene limestone just south of the crest appears to be marked by a steeply inclined normal fault that strikes N. 75° W. and dips southwestward. At other localities the Plaisance limestone is folded and crumpled like the upper Eocene limestone.

Fossils.—Some of the characteristic fossils of the Plaisance limestone are shown on Plates IX and X. The most common fossils are two species of Foraminifera, *Dictyoconus puilboreauensis* Woodring (Pl. IX, Figs. 3-5, 7-8) and *Dictyoconus codon* Woodring (Pl. IX, Figs. 1-2, 5-6; descriptions on pp. 608-609). At the type locality they are found in the basal conglomerate and at different horizons up to the highest beds exposed. *D. codon* is very similar to *D. egyptiensis* (Chapman), a characteristic fossil of the lower Mokattam group of middle Eocene (Lutetian) age of Egypt. No orbitoidal Foraminifera were found in the Plaisance limestone, so that its foraminiferal fauna is in striking contrast to the rich orbitoidal fauna of the upper Eocene limestone. Although the species of *Dictyoconus* are similar to Mediterranean species the Plaisance limestone contains none of the large nummulites that reach their culmination in the middle Eocene of the Mediterranean region. This absence of large nummulites is the most striking difference between the early Tertiary Foraminifera of the Mediterranean and West Indian regions.

The Plaisance limestone yielded the largest collection of echinoids obtained in the Republic. Though poorly preserved, some of them seem to be similar to lower Mokattam species. Some of the Plaisance mollusks are similar to species from the Mediterranean region. *Pseudomiltha haitensis* Woodring and Mansfield (Pl. X, Fig. 1), and *Chama engonia*

PLATE IX.

CHARACTERISTIC FORAMINIFERA OF THE PLAISANCE LIMESTONE (MIDDLE EOCENE).

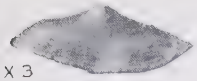
FIGURES 1, 2. *Dictyoconus codon* Woodring (p. 608). Side (1) and basal (2) views of type, × 3. U. S. G. S. station 9857. U. S. N. M. catalogue No. 350586.

FIGURES 3, 4. *Dictyoconus puilboreauensis* Woodring (p. 609). Side (3) and basal (4) views of type, × 3. U. S. G. S. station 9857. U. S. N. M. catalogue No. 350587.

FIGURE 5. *Dictyoconus codon* Woodring (large) and *Dictyoconus puilboreauensis* Woodring (small), × 3. U. S. G. S. station 9441.

FIGURE 6. *Dictyoconus codon* Woodring. Vertical section, × 20. U. S. G. S. station 9441.

FIGURES 7, 8. *Dictyoconus puilboreauensis* Woodring. Vertical sections, × 20. U. S. G. S. station 9441. Fig. 8 shows early spiral stage.



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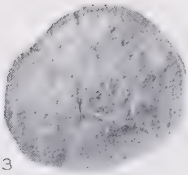

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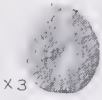

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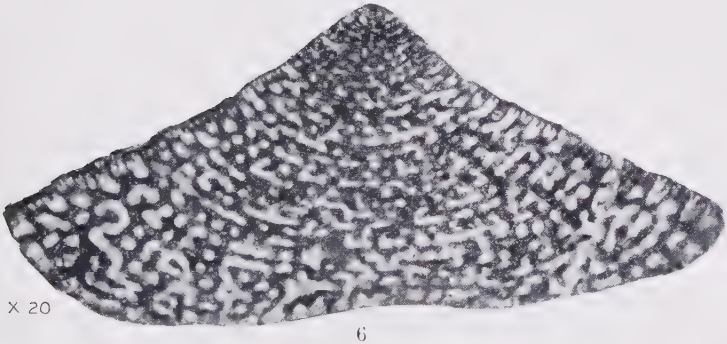

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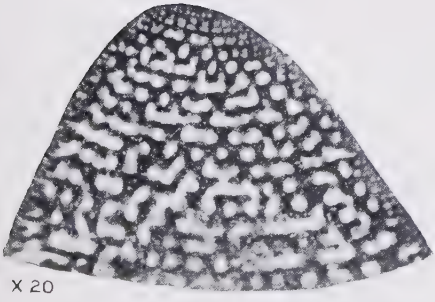

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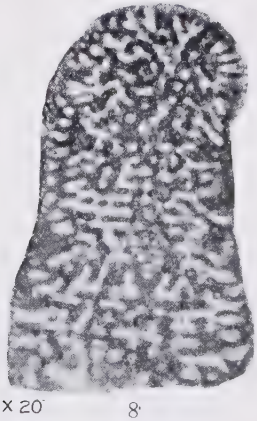

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CHARACTERISTIC FORAMINIFERA OF THE PLAISANCE LIMESTONE.

Woodring and Mansfield (Pl. X, Figs. 2, 3; descriptions on pp. 612-613) were collected at several localities.

Collections of fossils recently obtained in Jamaica by Dr. C. A. Matley, Government Geologist of Jamaica, show that the "Yellow limestone" of Jamaica is of the same age as the Plaisance limestone. The "Yellow limestone" fauna is very similar to the Plaisance fauna, but is more varied. Gigantic Cerithia, which are conspicuous in the "Yellow limestone," have not been found in the Plaisance limestone. Almost a century ago De la Beche[1] considered the "White limestone"[2] to be of the age of the Calcaire grossier of the Paris Basin—that is, middle Eocene (Lutetian).[3]

Stations—Plaisance limestone (middle Eocene).

9771 (B 260 F). Arrondissement of Plaisance, road from Plaisance to Ennery, at north foot of Mont Puilboreau, about 5 kilometers from Plaisance; altitude, 515 meters above sea level. J. S. Brown, collector. February 12, 1921.

9857 (B 260 Fa). Arrondissement of Plaisance, same locality as 9771. W. P. Woodring and J. S. Brown, collectors. February 25, 1921.

9888 (B 325 F). Arrondissement of Plaisance, same locality as preceding stations but from higher beds. J. S. Brown, collector. March 24, 1921.

9889 (B 326 F). Arrondissement of Plaisance, same locality as preceding stations but from higher beds. W. P. Woodring and J. S. Brown, collectors. March 24, 1921.

9858 (B 262 F). Arrondissement of Plaisance, road from Plaisance to Ennery, north slope of Mont Puilboreau, about 7 kilometers from Plaisance. J. S. Brown, collector. February 7, 1921.

9441 (H 6 V). Arrondissement of Plaisance, road from Plaisance to Ennery, north slope of Mont Puilboreau; altitude, 475 meters above sea level. T. W. Vaughan, collector. April 18, 1919.

9859 (B 263 F). Arrondissement of Plaisance, road from Plaisance to Ennery, north slope of Mont Puilboreau, about 8 kilometers from Plaisance; altitude, 620 meters above sea level. J. S. Brown, collector. February 24, 1921.

9860 (B 266 F). Arrondissement of Plaisance, road from Plaisance to Ennery, north slope of Mont Puilboreau, about 8.5 kilometers from Plaisance; altitude, 685 meters above sea level. W. P. Woodring and J. S. Brown, collectors. February 25, 1921.

9442 (H 7 V). Arrondissement of Plaisance, road from Plaisance to Ennery, north slope of Mont Puilboreau; altitude, 700 meters above sea level. T. W. Vaughan, collector. April 18, 1919.

9861 (B 267 F). Arrondissement of Plaisance, road from Plaisance to Ennery, north slope of Mont Puilboreau, about 10 kilometers from Plaisance; altitude, 905 meters above sea level. J. S. Brown and W. P. Woodring, collectors. February 25, 1921.

9991 (B 236 F). Arrondissement of Plaisance, crest of Mont Puilboreau. J. S. Brown, collector. February 16, 1921.

[1] De la Beche, H. T., Remarks on the geology of Jamaica: Geol. Soc. London Trans., 2d ser., vol. 2, pp. 143-194, pls. 18, 19, 21, 22, 1829. (See p. 171.)

[2] The lower part of the "White limestone" of De la Beche, which contained most of the fossils listed, was called the "Yellow limestone" in the report of the Jamaican Survey of 1869.

[3] Since this report was written Dr. C. T. Trechmann has published a description of the Yellow limestone and its mollusks: The Yellow limestone of Jamaica and its Mollusca: Geol. Mag., vol. 60, no. 710, pp. 337-367, pls. 14-18, 1923.

9871 (B 284 F). Arrondissement of Marmelade, large cave about 3 kilometers northeast of St.-Michel de l'Atalaye. J. S. Brown, collector. March 4, 1921.

9872 (B 285 F). Arrondissement of Marmelade, float on hill about 100 meters south of large cave, 3 kilometers northeast of St.-Michel de l'Atalaye. J. S. Brown, collector. March 4, 1921.

9873 (B 287 F). Arrondissement of Marmelade, south slope of mountains near plantation of United West Indies Corporation, 4 to 5 kilometers northeast of St.-Michel de l' Atalaye. J. S. Brown, collector. March 5, 1921.

9734 (W 268 F.) Arrondissement of Marmelade, trail leading northward into mountains from plantation of United West Indies Corporation, east of St.-Michel de l'Atalaye, about 1 kilometer from plantation. W. P. Woodring, collector. February 8, 1921.

9792 (W 316 F). Arrondissement of Gonaïves, road from Ennery to St.-Michel de l'Atalaye, west slope of Crête Salée, about 1 kilometer from crest. T. W. Vaughan and W. P. Woodring, collectors. March 4, 1921.

9952 (W 345 F). Arrondissement of Gonaïves, road from Ennery to St.-Michel de l'Atalaye, west slope of Crête Salée, altitude 580 meters above sea level. W. P. Woodring and J. S. Brown, collectors. March 24, 1921.

9951 (W 344 F). Arrondissement of Gonaïves, road from Ennery to St.-Michel de l'Atalaye, west slope of Crête Salée, altitude, 565 meters above sea level. W. P. Woodring and J. S. Brown, collectors. March 24, 1921.

9950 (W 343 F). Arrondissement of Gonaïves, road from Ennery to St.-Michel de l'Atalaye, west slope of Crête Salée; altitude, 535 meters above sea level. W. P. Woodring and J. S. Brown, collectors. March 24, 1921.

9753 (W 287 F). Arrondissement of Gonaïves, trail from Gros-Morne to Pilate, right bank of Les Trois Rivières, 2 kilometers above second crossing. W. P. Woodring, collector. February 16, 1921.

9754 (W 288 F). Arrondissement of Gonaïves, trail from Gros-Morne to Pilate, right bank of Les Trois Rivières, 50 meters above third crossing. W. P. Woodring, collector. February 16, 1921.

9892 (B 338 F). Arrondissement of Gonaïves, trail from Gros-Morne to Terre-Neuve, float at base of mountains near Savanne Moulin in Section Moulin (300 meters west of station 9891). J. S. Brown, collector. March 27, 1921.

9893 (B 339 F). Arrondissement of Gonaïves, float on trail from Gros-Morne to Terre-Neuve, 1 kilometer west of station 9892. J. S. Brown, collector. March 27, 1921.

9894 (B 340 F). Arrondissement of Gonaïves, float along trail about 1 kilometer north of little chapel in Section Moulin, north of Terre-Neuve. J. S. Brown, collector. March 27, 1921.

9859 (B 342 F). Arrondissement of Gonaïves, Memé Valley, float at Des Hommes prospects. J. S. Brown, collector. March 28, 1921.

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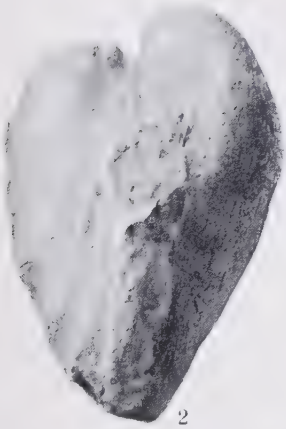

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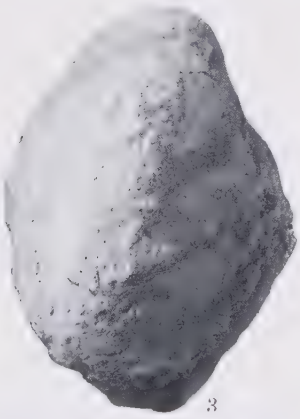

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SOME CHARACTERISTIC MOLLUSKS OF THE PLAISANCE LIMESTONE (MIDDLE EOCENE).

Figure 1. *Pseudomiltha haitensis* Woodring and Mansfield (p. 612). Type, ×1. U. S. G. S. station 9792. U. S. N. M. catalogue No. 350572.
Figures 2, 3. *Chama engonia* Woodring and Mansfield (p. 612). Two views of type, ×1. U. S. G. S. station 9792. U. S. N. M. catalogue No. 350573.

Fossils from Plaisance limestone (Middle Eocene).

Species.	Massif du Nord.																										Mont. de Terre Neuve.
	Plaisance.											Marmelade.				Gonaïves.											
	9771	9857	9888	9889	9858	9441	9859	9860	9442	9861	9991	9871	9872	9873	9784	9792	9952	9951	9950	9753	9754	9792	9892	9893	9894	9895
Foraminifera:																										
Nummulites (small sp.)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..
Dictyoconus puilboreauensis Woodring	×	×	×	×	×	×	×	×	×	×	×	×	..	×	×	×	..	..	..	×	×	..	..	..	..	..	..
Dictyoconus codon Woodring	..	×	×	..	..	×	×	×	×	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..
Corals:																										
Stylocoenia sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..
Stylophora n. sp. (massive form cf. S. ponderosa Vaughan)	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	×	×	..	..
Genus ?, fungid coral, cf. Haloseris	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..
Cladocora jamaicensis Vaughan	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×
Astreopora n. sp. (very small calices)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..
Goniopora sp. indet.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..
Echinii:																										
Linthia sp. cf. L. cavernosa de Loriol	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..
Schizaster ? sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..
Eupatagus n. sp. cf. E. mortoni (Conrad)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..
Plagiobrissus sp. cf. P. loveni (Cotteau)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..
Mollusca:																										
Gastropoda:																										
Volutospina sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..
Latrunculus sp. cf. L. stromeri Oppenheim	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..
Cassis ? sp.	×	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Amauropsis ? sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..
Pelecypoda:																										
Ostrea sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..
Spondylus sp. cf. S. dumosus Morton	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..
Spondylus ? sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..
Modiolus sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..
Cardita sp. cf. C. chmeietensis Oppenheim	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..
Chama sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..
Chama engonia Woodring and Mansfield	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	×	..	×	..	..	..	..	..	..	..	..
Pseudomiltha haitensis Woodring and Mansfield	..	..	..	×	..	..	..	..	..	×	..	..	..	..	..	×	×	..	×	..	..	..	..	..	..	..	..
Veneridae, genus ?	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Decapod Crustacea:																										
Zanthopsis ? sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..

UPPER EOCENE.

General Features.

Areal distribution.—Upper Eocene rocks cover large areas on most of the mountains in the Republic and on Gonave Island. (See Pl. I.)

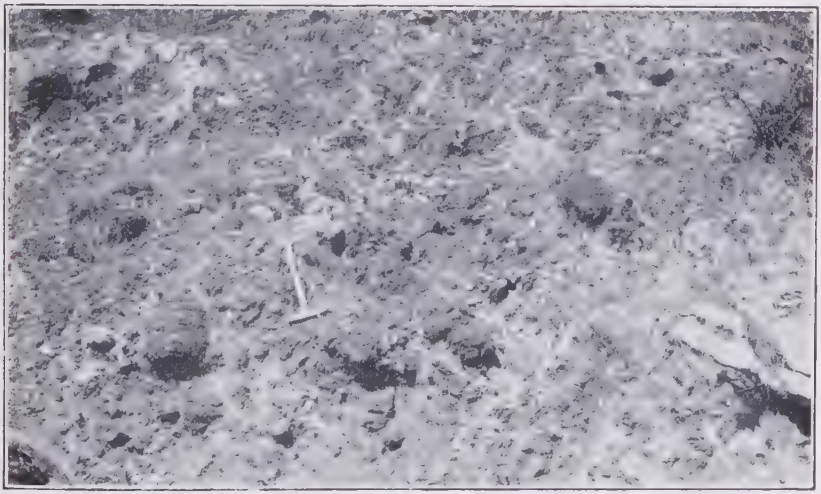
Stratigraphic relations.—The only observed contact of upper Eocene limestone with the Plaisance limestone appears to be marked by a fault (see p. 103). Upper Eocene limestone overlaps the Plaisance limestone and rests unconformably on the floor of igneous and other Mesozoic rocks. This overlap is shown in the relatively short distance between the northeast and southwest slopes of Mont Puilboreau.

Lithology.—The upper Eocene rocks consist almost entirely of limestone, but at some localities beds of shale, soft sandstone, and even coarse conglomerate are interbedded with the limestone, particularly at the base or in the lower part. A conglomerate generally lies at the base. It may be either thick and prominent or thin and inconspicuous. The type of limestone differs considerably at different localities and also at different horizons at the same locality. For this reason it seems inadvisable to name the upper Eocene limestones. The following are the most common types:

One type is white to yellow and has a porous chalky or sandy appearance, although unweathered specimens are rather hard. It breaks with a conchoidal fracture. The beds are generally rather regular and even and most of them range from 5 to 15 centimeters in thickness. Shaly partings are common, and some beds contain sandy detrital material and even coarse conglomerate. Chert lenses and concretions are common. Few of the chalky beds contain fossils, but certain beds of more granular limestone that show traces of detrital material contain abundant Foraminifera. Some of the cherts also contain Foraminifera. In weathering this rock leaves a gray or chalky soil and many reddish or brownish pieces of siliceous limestone. This type of limestone is well developed around the borders of the Montagnes de Terre-Neuve, on Morne Biénac north of Gonaïves, and along the railroad between Gonaïves and Ennery. In these regions it appears to form the lower or basal part of the upper Eocene, but part of it may be middle Eocene. It is probably equivalent to part of the coarse basal conglomerate that contains a few beds of limestone which occurs in great thickness at places in the Montagnes de Terre-Neuve.

Another type that is found in most of the larger areas where upper Eocene rocks crop out is a hard limestone that is gray on weathered and white on fresh surfaces. It occurs in reasonably regular beds ranging in thickness from 10 to 30 centimeters, but on weathered slopes or bluffs it usually appears massive. Some of the beds are composed of elongate nodules such as characterize the lower part of the Plaisance limestone. The beds contain little or no shale or other detrital material and generally very little chert. The surface is roughly pitted and fretted. Such rock is called roche-à-ravet. The rock yields a red clay soil. This type of lime-

A. UPPER EOCENE LIMESTONE NEAR LA PIERRE.
The limestone has been partly dissolved and recemented, forming a solution breccia.



B. CONGLOMERATE AT BASE OF UPPER EOCENE LIMESTONE AS EXPOSED IN MOULIN NEAR THE TRAIL FROM GROS-MORNE TO TERRE-NEUVE.
The cobbles are volcanic rocks.

stone commonly contains Foraminifera, some mollusks, and a few corals. It is well developed south of Terre-Neuve on the road to Gonaïves, along the crest of the Montagnes Noires between Dessalines and Paul, near Montagnac east of Dame-Marie, and at other places in most of the mountains. In the Gonaïves region and elsewhere it overlies limestone of the first type and forms the upper part of the upper Eocene deposits.

A third type consists of very evenly bedded cherty limestone, which at many places contains beds and lenses of nearly pure chert. The beds are 10 to 15 centimeters in thickness. The rock is white to bluish, its color depending probably on the proportion of siliceous material it contains. It is very hard and breaks with a splintery conchoidal fracture. Such beds contain little or no shale or other detrital material, except near the base. At some localities beds of white porous granular limestone are interbedded with cherty limestone. Chert fragments are conspicuous in the residuum from this limestone. The chert may contain Foraminifera, and well-preserved Foraminifera are found at some places in the granular limestone. This type of limestone is common in the Port-Salut Peninsula near Cavaillon and along the south coast from Marigot eastward to the Dominican border. Similar rock in the mountains just south of Anse-à-Veau contains many beds of dark-blue or black chert.

Other types of upper Eocene limestone might be distinguished or different features might be chosen as criteria for their separation, as there are many variations from the types described.

The solubility of most of the upper Eocene limestones accounts for their great changes in physical appearance, which are especially conspicuous near the surface but at places probably extend to great depth. The covering of soil, which is red or white, chalky or cherty, has been mentioned. Other features include pitted or honeycombed surfaces, sharp pinnacled projections, and surfaces coated by a crust of dissolved and redeposited calcareous material, which may contain excellent specimens of Recent shells or impressions of plants. Cobbles of limestone embedded in a calcareous crust along trails may simulate a conglomerate. Cavities dissolved in the limestone are commonly refilled with soil and sediment that is recemented with calcareous material, producing a mass of rock that may aptly be termed solution breccia and that is illustrated in Plate XI, *A*. Such solution breccias are common in all areas underlain by the second type of limestone described on page 108.

Thickness.—The structure of the upper Eocene limestone is so complex and the areas in which it lies at the surface are so difficult to explore fully on account of their ruggedness and the thick growth of vegetation that no accurate estimate of its thickness was obtained. In all the principal areas where it is found, however, it has a thickness of at least several hundred meters and at a few places of 1,000 to 2,000 meters. The section on the Bras-à-Gauche south of Jérémie is believed to represent at least 1,300 meters of limestone. Limestone at least 500 meters thick is

exposed on the north slope of the mountains immediately south of Rendez-vous, on the trail from Pétionville to Furcy. (See p. 131.)

Structure.—The upper Eocene limestone is nearly everywhere sharply folded. In general, as has already been stated, the mountain ranges consist of huge compound anticlines (such as are commonly but incorrectly called anticlinoria) or are remnants of such anticlines modified by erosion. At some places the limestone is intensely crumpled and small thrust faults are common, and at a few places there are probably high-angle thrust faults of considerable magnitude. The folding has here and there caused shearing and produced a sheeted structure in the rock that makes the determination of the bedding difficult or impossible.

Description by Regions.

Massif du Nord.

Morne du Cap.—The crest of the Morne du Cap is formed by a ridge that trends east and west and that is several kilometers in length and from 100 to more than 200 meters in height. The crest and most of the north slope of the mountain are covered by limestone of upper Eocene age, which lies unconformably on volcanic rocks and on an impure cherty limestone of supposed Cretaceous age. The basal contact of the limestone along the short, steep escarpment south of the crest was not examined but is plainly visible from a distance and apparently is 50 to 100 meters below the summit of the ridge. On the north slope the limestone in most places extends down to the sea. It therefore seems that the limestone dips seaward and overlies the older rocks.

A basal conglomerate marks the contact of the upper Eocene and older rocks. This conglomerate was found in place at only one locality, near Source Cinq Carreaux and Source d'Aubry of the Cap-Haïtien water supply. The exposure is not very large but indicates a thickness of probably 50 meters or more, as the beds apparently are steeply titled. The rock is hard and dark and consists mainly of chert, though in part of fragments of volcanic rock. Beds half a meter thick were noted. At another locality, about 1 kilometer west of Source Belair, float of a similar conglomerate was found near the base of the limestone. It contains a greater proportion of fragments of volcanic rock, generally subangular and very firmly cemented.

The main mass of the limestone appears to resemble the second type described on page 108. It is hard and is gray on weathered and white on fresh surfaces. Some of it appears to be crystalline, and it contains coarse crystals of calcite. The rock is generally massive on weathered exposures. Its surface is pitted with solution cavities, and at almost every locality observed it consists of huge blocks left by solution, making the land surface very jagged and uneven. Such features are conspicuous west of the lighthouse at Fort Picolet. No reliable estimate of its thickness is possible, but

the upper Eocene limestone is at least a few hundred meters thick. Upper Eocene Foraminifera were collected at four localities. (See list at p. 144, stations 9854, 9853, 9847, 9798.)

Near Dondon.—Upper Eocene limestone forms a high mountain just west of Dondon and extends northward beyond the Citadelle of Christophe, capping a sharp, narrow ridge known as the Bonnet-à-l'Évêque. The limestone overlies volcanic rocks, old argillites and upper Cretaceous limestone with angular unconformity. On the trail to the Citadelle of Christophe and the Bonnet-à-l'Évêque the contact is at an altitude of about 650 meters above sea level, but farther south the upper Eocene limestone descends to the border of the valley of Dondon, which is only about 400 meters above sea level.

At the base of the upper Eocene limestone is a conglomerate, which is exposed at several places on the trail leading down from the Citadelle to Dondon in the first half a kilometer south of the place where the trail branches from that leading down to Milot. Near the fork in the trail are dark sandy beds that may possibly belong in the basal upper Eocene. A little farther south hard conglomerate occurs in beds ranging from 15 to 40 centimeters in thickness. These beds are exposed again about half a kilometer from the fork of the trail in contact with upper Cretaceous limestone, which they apparently overlie. A sample of conglomerate from the last exposure contains undetermined species of *Orthophragmina*. The hard conglomerate in both exposures is composed mainly of a gray or bluish calcareous matrix which cements a considerable proportion of small pebbles of the older igneous rocks, Cretaceous (?) argillites, and upper Cretaceous limestone containing rudistid mollusks. Float from the basal upper Eocene conglomerate was found on the trail to Milot.

The limestone above the basal beds in this region is very similar to that on the Morne du Cap and contains the same Foraminifera. It most closely resembles that of the second type described on page 108. It is gray and appears massive on all weathered surfaces. The surfaces are pitted by solution cavities, and the whole mass is commonly honeycombed by caverns. Several such caverns were seen along the trail to the Citadelle.

The thickness of the limestone, at least on the mountain just west of Dondon, must aggregate several hundred meters.

The only fossils found were Foraminifera. Good specimens were obtained from float just southwest of Milot (see list opposite p. 144, station 9744) and from a block of the masonry in the Citadelle (station 9797), which is in part built of limestone from the mountain to the south.

To the east and south of Dondon there is supposed upper Eocene limestone of a type considerably different from that to the west and north and more similar to the first type, described on page 108. This rock occurs in very even beds, which are generally 10 to 20 centimeters thick, though at some places they reach 30 centimeters. Some beds are white and have

a chalky granular appearance, but most of them are dense and full of bluish chert lenses. The beds are sharply folded and at places show a sheeting transverse to the bedding. Good exposures are found on the mountain slopes east of Dondon and south of Dondon on the trail to St.-Rafaël in bluffs along Rivière Bouyaha.

This rock is apparently overlain by middle Oligocene limestone, and it may therefore be lower Oligocene instead of upper Eocene.

Arrondissement of Borgne.—The eastern part of the coastal ridge between Anse-à-Foleur and the plain at the mouth of Rivière de Port Margot, in the arrondissement of Borgne, is composed of upper Eocene limestone, which rests on basaltic volcanic rocks. A conglomerate at the base of the limestone contains pebbles of the volcanic rock and also of limestone, probably of Cretaceous age. The lower part of the limestone contains beds of shale and sandy detrital material, and the upper part consists of hard gray limestone and thinner beds of dense porcellanous limestone. Upper Eocene Foraminifera were collected at a locality on the west side of Baie de la Rivière Salée. (See list opposite p. 144, station 9769.) The limestone along the coast between Anse-à-Marigot and Acul Bay probably is upper Eocene, but was not examined.

Northwest Peninsula.

Bombardopolis Plateau.—Rocks of probably upper Eocene age were found on the Bombardopolis Plateau along the trail from Baie de Henne to Bombardopolis, where they are well exposed on three or four north-south ridges, described on page 370. These rocks appear to overlie the reworked fragmental volcanic rock described on page 266, but their exact relations are obscure. They are overlain unconformably by Quaternary coralliferous limestone.

The supposed Eocene rocks consist mainly of dark to bluish very cherty limestone, in thin and even beds, but at some places they contain thick layers of fine, dark-brown sandy material. The sandy material appears to contain fragments of igneous rocks, which are probably derived from the same source as the fragments of the underlying tuffaceous rock. The beds are sharply folded and generally strike a little west of north, but they dip either to the east or west at angles of about 30°.

According to Lütgens[1] the same series of rocks occurs on Morne Chien, west of Baie de Henne. His description[2] shows that apparently similar rocks crop out on the edge of the plateau along the trail leading down to La Plateforme. He believed, however, that the basaltic rocks underlying the limestone and the fragmental volcanic beds at or near the base of the limestone are of late Tertiary or early Quaternary age.

[1] Lütgens, R., Geog. Gesell. in Hamburg Mitt., Band 32, pp. 68-69, fig. 5, 1919.
[2] Idem. p. 73, fig. 7, 1919.

Farther north, near Bombardopolis, a white chalky limestone is poorly exposed at several localities. This limestone probably underlies the Quaternary coralliferous limestone and may also be upper Eocene.

Montagnes de Jean Rabel.—Upper Eocene limestone forms a thick cap on the top of the Montagnes de Jean Rabel, south of the town of Jean Rabel, along the crest of the Northwest Peninsula. It rests unconformably on quartz diorite and volcanic rocks and is overlain by Oligocene and Miocene beds.

At the base of the upper Eocene limestone lies a conglomerate composed of fragments of the underlying igneous rocks. The only good exposure of this conglomerate that was seen is about 5 kilometers southwest of Jean Rabel, on Rivière Cadet. The conglomerate pebbles generally are less than 10 centimeters in diameter and are well rounded. The rock is firmly cemented, well bedded, and has a thickness of about 35 meters. It grades upward into sandy limestone that contains much detrital material. This zone is about 50 meters in thickness and grades upward into pure white limestone like that of the second type described on page 108. This rock apparently constitutes the great mass of the limestone in this region.

The limestone and conglomerate on the Rivière Cadet are tilted northeastward at angles of 15° to 30°, and the limestone on the Jean Rabel–Anse Rouge trail dips northward. The major structural feature of the mountain range appears to be an anticlinal arch.

Foraminifera, particularly Cuban species of *Orthophragmina,* are abundant in the conglomerate and limestone at most of the places examined. (See list at p. 144, stations 9795, 9842, 9843, 9845, 9796 and 9964.)

Montagnes de Terre-Neuve.—Upper Eocene deposits cover most of the Montagnes de Terre-Neuve, although many patches of the underlying igneous rocks are exposed, and in the Terre-Neuve mineral district the igneous rocks are predominant at the surface. The upper Eocene deposits consist mainly of limestone, which rests as a thick cap unconformably on a basement of basaltic and andesitic rocks. The lower part of the formation comprises a thickness of several hundred meters of impure beds which grade from coarse conglomerate, composed almost entirely of igneous débris, into thin-bedded limestone containing beds of sand and shale. Some of the conglomerate and thin-bedded limestone may be middle Eocene. The upper part of the series, also some hundreds of meters in thickness, consists of purer limestone, generally in thicker beds and more commonly fossiliferous. The thickness of the entire series was not measured, even roughly, but it is probably not less than 1,000 meters. Successively higher beds overlap the lower beds, as the upper pure limestone at many localities in the central part of the region rests almost directly on the old igneous landmass. The lower beds are most widely exposed and are thickest around the borders of the mountain mass, whereas the purer limestone is predominant in the interior. This relation is

significant not only stratigraphically and structurally but also because it seems to afford some indication that the old landmass had its axis in part in the same area that constitutes the present axis of the mountains. However, the existence of a trough in the central part of the region must be postulated to account for the anomalous development of thin-bedded impure limestones on Morne Miguinda.

Exposures of these rocks as they were found at a number of different localities are described below.

Some of the best exposures of the basal conglomerate are found in Section Moulin, Commune of Gros-Morne, northeast of Terre-Neuve, in the deep valley drained by Rivière Lhormand. About 400 meters northwest of the Chapel, which is in the western part of this valley (for location see Pl. II, in pocket), the conglomerate is exposed on low hills that border a trail. It contains many cobbles, 20 to 30 centimeters in diameter, composed of the volcanic rocks common in the region (Pl. XI, *B*). Interbedded with this coarse material are local beds of shaly and impure limestone, some of them 1 to 2 meters thick. On the Terre-Neuve trail 500 to 1,000 meters southeast of the Chapel there are many thin beds of impure bluish limestone and sandy detrital material, which overlie patches of weathered igneous rock.

About 4 kilometers east of this same Chapel and about 1 kilometer west of a village called Savane Moulin the Rivière Lhormand passes through a gorge in the easternmost ridge of the Montagnes de Terre-Neuve, at the border of the Trois Rivières valley, along the main trail between Gros-Morne and Terre-Neuve. Near the west end of the gorge a reddish porphyritic andesite is exposed in the stream bed and is overlain by a conglomerate composed of igneous material. The conglomerate extends downstream for perhaps 200 or 300 meters and apparently dips eastward. It grades upward through sandy and conglomeratic limestone into pure limestone of the massive type, which crops out to the east in the main part of the gorge. The exposures of conglomerate in the stream bluffs are masked by talus. Much better exposures are found directly to the south, on the southwest slope of the ridge through which the gorge has been eroded. Here the conglomerate contains coarse and angular fragments, as well as some well-rounded pebbles, and appears to be several hundred meters thick.

Similar basal conglomerate of comparable thickness is found several kilometers to the southeast, probably along a part of the same ridge. The conglomerate is associated with the manganese deposits in the vicinity of Morne Macat. (See p. 470.) It crops out on the west slope and partly on the crest of this somewhat broken ridge for an undetermined distance. The observed extent is more than 3 kilometers. The conglomerate contains many large, rough cobbles of dark andesitic rocks, and also a considerable amount of fine sand, the whole mass being rather poorly sorted. The underlying volcanic rock appears to be exposed on the south end of

Morne Macat, but near the north end, on the west slope, the conglomerate seems to rest on a bluish metamorphosed shaly limestone, fragments of which it contains. The beds of conglomerate generally dip eastward or northeastward, and on the crest of the ridge they are overlain in places by white limestone, probably of the pure massive type. Between the two there is a transition zone of sandy and conglomeratic limestone, from which the upper Eocene Foraminifera listed at page 144 (stations 9868, 9869, and 9870) were collected on the crest of Morne Macat. The upper Eocene rocks in this region are cut off to the east by a fault, and at places the basal conglomerate is in contract with Oligocene rocks, as described on page 121.

No other exposures of the basal conglomerate were found in the region. Traces of it were noted about 1.5 kilometers southeast of Terre-Neuve, on a trail that skirts the southwest side of Morne Miguinda, near the northwest end of that mountain. The material is composed of fragments of igneous rocks interbedded with limestone, but the rock has been brecciated by faulting, so that the relations are not clear. The fossils listed opposite page 144 (station 9800) are from this exposure.

Traces of conglomerate beneath the upper Eocene limestone were also found about 3 kilometers west of Terre-Neuve, in a ravine south of Morne Avocat.

In the interior of the Montagnes de Terre-Neuve the conglomerate either is thin and masked by talus or is composed entirely of fragments of igneous rock and can in few places be distinguished from weathered volcanic rock.

As suggested on page 102, some of the conglomerate in the eastern part of the Montagnes de Terre-Neuve may be of middle Eocene age.

The best section of the thin-bedded limestone containing detrital material is exposed on the south slope of Morne Biénac, a prominent isolated mountain directly north of Gonaïves. This face of the mountain forms a cuesta slope, on which the rocks strike approximately east and west and dip 15°–30° N. On the southwest slope the beds are exposed almost continuously from an altitude of about 90 meters above sea level to the top of the mountains, at about 350 meters above sea level. The lowest exposed beds are thin-bedded yellowish chalky or sandy limestone with a little interbedded clay.

At an altitude of about 160 meters above sea level the thickness of the beds increases rather abruptly to perhaps 35 centimeters, and at this horizon there is a conspicuous bed of conglomeratic limestone about a meter thick, which was traced for several hundred meters along the mountain side. It is composed of small pebbles, most of them less than 3 centimeters in diameter, of white or yellowish limestone that resembles the underlying beds and of dark-blue chert and smaller, badly weathered fragments of igneous rock. The pebbles are subangular to well rounded and are firmly cemented in a calcareous matrix. Foraminifera apparently

embedded in the matrix were collected at two neighboring localities from this bed (see list opposite p. 144, stations 9848 and 9851). The beds below the conglomerate may be of middle Eocene age.

The conglomerate is overlain by a meter or more of crumbly gray sandstone, followed by thin beds of limestone and by shaly or sandy beds much like those on the lower slope of the mountain and containing no fossils. These beds extend to an altitude of about 300 meters above sea level. In the upper part they became whiter and more chalky and contain less shale.

Capping the mountains and overlying the thin-bedded limestone lies a massive gray limestone, 40 to 50 meters thick, which has been broken down by solution and redeposition of material into a typical solution breccia. It is pitted and pinnacled in odd shapes, and has been so filled with red clay and stained by iron oxides that it has a peculiar reddish tint, noticeable even from the plain to the south. Much crystalline calcite has also been deposited in the cavities. This rock extends an undetermined distance northward down the dip slope of the mountain, suggesting that its dip conforms to that of the underlying beds. It is believed to be the same as the pure massive type of limestone described on page 108. The only fossils obtained were specimens of a poritid coral of massive growth form. (Station 9850.)

The thickness of the thin-bedded limestone containing detrital material exposed is fully 400 and probably more nearly 500 meters.

About 1 or 2 kilometers east of the section just described, on the lower slope of Morne Biénac, there is a very prominent vertical cliff, about 50 meters high, which is especially conspicuous from the harbor. The base of this cliff was examined hastily. It appears that the cliff consists of massive grayish limestone, partly conglomeratic, which probably dips northward. This bed probably is lower in the section than any of those farther west, but its exact relations are not clear.

The eastern face of Morne la Pierre, although not examined closely, bears a striking resemblance to the south slope of Morne Biénac. It is a long and regular escarpment that rises gradually from the sea on the south to a height of about 600 meters on the north, west of Morne Soleil. The lower slopes appear to be composed mainly of the thin-bedded limestone. About 100 or 200 meters below the top of the escarpment stands a conspicuous, very reddish bluff, apparently overlain by gray or massive limestone. The reddish color of the bluff doubtless is due to the formation at the contact of the two types of limestone of a solution breccia similar to that on the top of Morne Biénac.

Thin-bedded limestone similar to that on Morne Biénac occupies the upper part of the south slope and all the north slope of Morne Soleil, the first ridge crossed by the trail from Gonaïves to Terre-Neuve, north of Gonaïves. On the south slope and near the summit it contains more shale and sandy material than is common on Morne Biénac, at some places

enough to constitute fully half of the section. About halfway up the south slope there is an exposure of badly weathered amygdaloidal basalt. The limestone beds overlie the basalt, probably unconformably. Only talus is exposed on the lower slope. Near the foot of the north slope of Morne Soleil, along the trail, the beds become much thicker and contain less detrital material. One bed of semicrystalline limestone in this section contains many small undetermined Foraminifera. The summit of Morne Soleil, which rises considerably above the trail, probably has a cap of the more massive limestone. The rocks along the trail are complexly folded, and the total thickness of the beds can not be estimated.

Just north of Morne Soleil, on the trail to Terre-Neuve, lies a deep valley, chiefly soil-covered, known as Mare-à-Colas. On the slope between Mare-à-Colas and the community called Figuier there are a number of exposures of soft brown sandstone or fine conglomerate containing pebbles of basalt and limestone, generally not more than 2 or 3 centimeters in diameter. The rocks appear to be interbedded with chalky limestones. Near the top of the main ascent, about 2 kilometers southeast of Figuier, there are some more massive limestone beds from which the Foraminifera listed under station 9827 at page 144 were obtained. All these beds appear to dip from 15° to 40° southeastward, down the slope of the mountain.

Morne Blanc, which is scarcely more than a hill, on the north shore of Gonaïves harbor, is composed almost entirely of the thin-bedded and clastic type of limestone, apparently identical with that on Morne Biénac. The surface of a bed on the north slope of the hill is pitted with numerous regular depressions that were probably made by raindrops. Near the summit of the north slope, at an altitude of 90 or 100 meters above sea level, a bed of crystalline limestone about a meter thick, containing a few small pebbles of igneous rock, yielded Foraminifera similar to those from the bed of conglomerate on Morne Biénac. (See p. 144, station 9735.) Near the seashore on the southwest point of this mountain the rock is well exposed at a number of abandoned quarries. In the quarries there is one unusually massive bed of limestone about 2 meters thick. At this locality the thin-bedded yellowish limestone containing sandy or shaly beds grades upward conformably into very white dense chalky limestone, also thin-bedded, which at many places shows a peculiar sheeted structure transverse to the bedding. There is no shaly material in this rock. On Morne Blanc the beds are generally tilted 15° to 20° in different directions, generally southeastward. There are a few very short and sharp flexures that have almost developed into thrust faults.

Nearly all the south end of Morne la Pierre, along the trail from Gonaïves to La Pierre, is composed of massive gray limestone, very much altered by weathering, which at many places forms the typical solution breccia described on page 109 and shown in Plate XI, *A*, and which closely resembles the rock capping Morne Biénac. The bedding is determinable at only a few places. The only fossil obtained was a coral. (See p. 144,

station 9737.) Beautifully preserved Recent shells of the genera *Urocoptis* and *Chondropoma* are included in the fillings and coatings of the breccia.

At La Pierre a small valley cuts a deep notch in the steep slope down to the coast. The lower part of this valley, apparently up to an altitude of 50 to 100 meters above sea level, is underlain by a pure white chalky sheeted limestone, which is believed to be equivalent of that in the upper part of the section on Morne Blanc. This rock yields a very pure white clay soil. It is definitely overlain by the more massive type of limestone forming the solution breccia, and the massive limestone appears to constitute the mountain heights back from the coast. La Pierre Spring, the source of the water supply of Gonaïves, issues at the contact of the two types of limestone in the bed of the Ravine la Pierre and owes the position of its outlet to the presence of the underlying less pervious chalky limestone. (See p. 591.) Higher in the section the overlying limestone, which can be traced for some distance up the ravine, appears to be less brecciated and probably grades into the pure massive type of limestone common in the interior of the Montagnes de Terre-Neuve.

Limestone of the thin-bedded type, together with much sandy and shaly material apparently derived from the erosion of basalt, is widely exposed in the valley of Rivière Bras-à-Droit northwest of the Montagnes de Terre-Neuve and around the borders of the Arbre Plain from the Sources Chaudes eastward and southeastward for several kilometers. Near Philippe, on Rivière Bras-à-Droit, half or more of the section appears to consist of detrital material. At a locality about 2 kilometers southeast of Philippe the limestone appears to be interbedded with basalt, but this relation may be due to a strike fault. Upper Eocene Foraminifera were collected at this locality (see list at p. 144, station 9824) from a bed that probably belongs in the thin-bedded and clastic type of rock.

Good exposures of the thin-bedded limestone are found on the south bank of Rivière Colombier about 1 kilometer west of Source Marianne and beyond. The rock is rather cherty. It appears to be in a fault contact with the pure massive type of limestone to the east. The fault trace occupies a deep ravine that trends N. 15° E. The thin-bedded limestones dip northwestward about 45° from an escarpment along this ravine. The presence of the massive limestone is indicated by huge weathered blocks lying on the ground. It seems that a thrust fault would be necessary to explain this contact, and it is possible that the thin-bedded limestone is overturned along the contact.

On a trail leading to the Sources Chaudes, about 2 kilometers southwest of Source Marianne and just north of a settlement called Petite Place, there is an isolated series of low ridges of the massive limestone that contains many Foraminifera. (See list at p. 144, station 9828.) The massive limestone appears to be surrounded by the thin-bedded type of limestone that contains much detrital material.

With the exception of that on Morne Miguinda (see below) the limestone in the high interior ranges of the Montagnes de Terre-Neuve appears to belong exclusively to the purer massive or thick-bedded type that carries little or no shaly or sandy material. At some localities, apparently near the base of the limestone, there are thinner beds that contain nodules or lumps. These beds were noted in the Section Bois-Neuf northwest of Terre-Neuve and on Rivière Bassin between Memé and Bassin. The more typical limestone is exposed in bluffs, in places 100 to 300 meters high, along Rivière Colombier west of Terre-Neuve from Bois-Neuf to Source Marianne. Some beds contain numerous Foraminifera and others contain no fossils. Stations 9825 and 9826 are in this region. (For lists see p. 144.) The rocks in this region are sharply folded, and strikes appear to vary a great deal. Other collections of fossils from the Terre-Neuve valley are listed opposite page 144 (stations 9813 and 9814).

Equally good exposures are common along the trail between Terre-Neuve and Gonaïves, in the region between Dolan and Darane, where there are many high bluffs. The Foraminifera listed at page 144, station 9821, were collected from a cliff near Dolan. Around Darane, which is near the crest of the divide on this trail, there are many large, flat sinkholes surrounded by cliffy slopes, about 200 meters high, of the pure thick-bedded limestone, the bedding being approximately horizontal. This locality is not far from Figuier, Morne Soleil, and the north end of Morne la Pierre, where the massive limestone appears to overlie the thin-bedded limestone, and it seems probable that at this locality the sinks have been formed on the soluble massive limestone, which overlies less soluble chalky and impure limestone. The less soluble limestone doubtless underlies the flat-bottomed sinks and prevents their enlargement downward, so that they have begun to expand laterally.

Foraminifera (see list, p. 144, station 9816) were obtained from massive limestone on the mountain slope northeast of Memé. In a gorge along Rivière Bassin, about midway between Bassin and Memé, the pure massive or thick-bedded limestone forms high cliffs. Other exposures in Section Moulin and on Morne Macat are described on pages 114-115.

The limestone on Morne Miguinda, a comparatively low mountain spur in the central part of the Montagnes de Terre-Neuve, a short distance southeast of the town of Terre-Neuve, does not conform exactly to any of the other types but probably should be correlated with the thin-bedded and detrital limestone of Morne Biénac and elsewhere. The mountain extends northwestward as a spur from Morne Dumuraille and is flanked on either side by deep, narrow valleys, so that it forms a rugged ridge. It appears to be composed almost entirely of rather cherty and siliceous limestone in even beds that range in thickness from 1 to 20 centimeters and are separated by shale partings hardly as thick as the limestone beds. The rock is yellow or bluish. It has been greatly fractured and the joints

are usually cemented with calcite. In weathering many polygonal blocks are broken off or etched along the bedding planes, giving the surface an unusually rough, jagged appearance. No fossils could be found in the limestone, but possibly those in the conglomerate near the west end of the mountain may come from the base of these beds. The rocks over most of the mountain appear to stand nearly vertical.

Still another rather divergent type of limestone is found on Morne Bouvard, an isolated ridge about 300 meters high along the coast between La Pierre and Coridon. This mountain is composed of a limestone that is black outside and commonly very dark inside. From a distance the rock looks like a lava. It is weathered into peculiarly pitted, pinnacled, and jagged forms and is very hard and dense. This rock contains an unusual species of *Orthophragmina,* which is found also on Morne Grammont (see list, p. 144, stations 9865, 9866, 9867), where the lithologic type is the same. It is inferred that this limestone is merely a phase of the lighter colored pure massive limestone found in the upper part of the normal section, especially as there is some indication on Morne la Pierre of a gradation phase between the two types.

The relation of the structure in the central part of the Montagnes de Terre Neuve to the ore deposits of the Terre-Neuve district is considered on pages 432-433 and is illustrated by figures 27 and 28, pages 442 and 444. As a whole the Montagnes de Terre-Neuve constitute a broad, gentle anticlinal arch trending northwestward. Numerous minor folds are superimposed on this arch, which is modified near its crest by a deep synclinal trough corresponding approximately to the depression along Terre-Neuve and Memé valleys. On both sides of this syncline the base of the upper Eocene limestone lies from 600 to 1,000 meters above sea level, but the dip on the flanks carries the pure massive limestone down from an altitude of 200 to 300 meters above sea level on the northeast, at the border of the trough of the Trois Rivières Valley, to sea level at many places on the southwest.

The crest of the major arch does not seem to plunge much in either direction, and deep erosion has cut down to the lower part of the series if not to the underlying bedrock both on the southeast, at Morne Soleil and Morne Biénac, and on the northwest, in the valley of Rivière Bras-à-Droit.

The anticlinal flank is broken on the northeast by one of the most prominent faults yet recognized in the Republic. This fault is exposed on the trail between Gros-Morne and Terre-Neuve, about half a kilometer west of Savane Moulin, near the entrance to the gorge cut by Rivière Lhormand in the low front range of the Montagnes de Terre-Neuve. (See Pl. II, in pocket.) Along the trail the fault runs along a low ridge. It trends about N. 55° W. and seems to dip steeply northeastward, but this observation has not been verified. On the northeast is pure white unfos-

siliferous limestone, of chalky appearance but dense, apparently thin-bedded and prominently sheeted. It resembles the chalky limestone found at La Pierre and elsewhere, supposedly the middle of the upper Eocene beds, but as apparently identical rock occurs in the Oligocene, and as upper Oligocene rocks are found in the lowland to the east, this limestone is tentatively correlated with the Oligocene. Southwest of the fault is massive gray limestone of upper Eocene type containing abundant Foraminifera (see list, p. 144, station 9891). For 2 or 3 meters along the fault this limestone is somewhat silicified and is largely replaced by brown or yellow limonite. It also contains black stains, probably of manganese minerals. The pure white limestone strikes about N. 75° W., and dips 25° northeastward. The bedding of the massive limestone is not apparent, but the structural and topographic features to the west indicate that it dips northeastward toward the fault, as the basal conglomerate of the upper Eocene is exposed not far away at higher altitudes.

A few kilometers south by east, along what is probably the continuation of the same ridge, which strikes out into the Trois Rivières Valley, the fault was found on Morne Macat, where it is intimately related to the deposit of manganese described on pages 470-475. Near this place the white sheeted unfossiliferous limestone, of supposed Oligocene age, was found east of the fault, which strikes about N. 20° W. West of the fault the crest of the ridge is formed of upper Eocene basal conglomerate, which is overlain by small patches of grayish limestone containing upper Eocene Foraminifera. The sheeted limestone to the east stands nearly vertical. The gray limestone and conglomerate to the west dip 20° or 30° northeastward toward the fault. The fault plane is very steep but probably dips eastward. The fault trace in this locality is marked by a reef of altered limestone, much of which is replaced by jasper and by oxides of iron and manganese. It was followed for a distance of about 3 kilometers.

Further indications of this fault were found still farther south, north of the road that branches from the Gonaïves-Gros-Morne road and goes northwest to Bassin. North of a dry ravine that runs eastward past the north end of Morne d'Anneau is a bluff, 20 meters high, formed of the white thin-bedded unfossiliferous limestone, in beds that strike northward and stand vertical. A short distance to the west are andesites and other volcanic rocks. No search was made for the fault, but it doubtless comes in somewhere in the intervening space. Its trend in this locality appears to have changed to nearly north.

This southernmost locality at which the fault was noted is about 14 kilometers from its exposure near Savane Moulin, and from this point it appears to extend a considerable distance both northward and southward. The throw of the fault is apparently equal to at least the total thickness of the upper Eocene series, certainly several hundred meters. It is probably a normal fault, although normal faults so great appear to be unusual in Haiti, the thrust fault being the more common type.

Some notable faulting has undoubtedly occurred along the central syncline in the Terre-Neuve district, but its details were not traced out, and indeed the work of tracing them would be very difficult. Faults are suspected to exist at other places, particularly at the contact of massive with thin-bedded limestone west of Source Marianne.

Valley of Rivière d'Ennery.

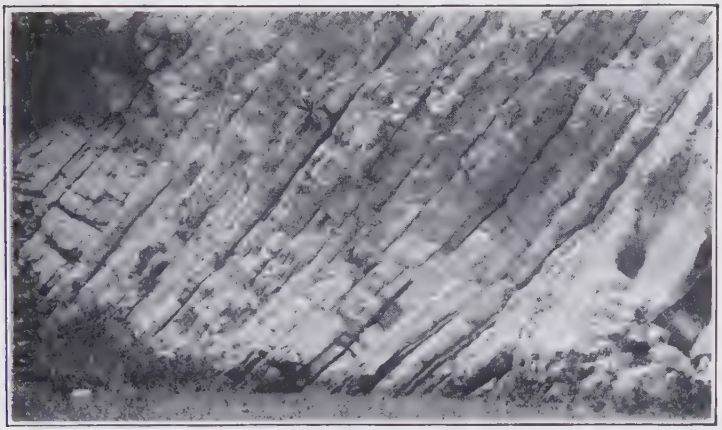
The valley of Rivière d'Ennery, as the term is here used, includes the mountain slopes north and south of that stream, the north slope belonging to the province of the Massif du Nord and the south slope to the Montagnes Noires. Most of the surface rocks in this area are of Upper Eocene age. In their lithology and fauna they resemble the upper Eocene rocks in the Montagnes de Terre-Neuve.

At the border of the plain near Gonaïves, on a small hill just north of the road to Ennery, thin-bedded sandy limestone similar to that on Morne Biénac rests on dark basalt. Farther east, where the road crosses a low ridge at the edge of the mountains, there are crumpled thin-bedded limestones and shaly beds, probably also the same as those on Morne Biénac.

The same beds of limestone crop out in numerous cuts along the railroad to Ennery and at many localities farther east, toward Ennery. A railroad cut west of Passe Reine along the south side of Rivière d'Ennery exposes white, dense limestone in thin and very even beds, separated by beds of shaly limestone. (See Pl. XII, *A*.) The Foraminifera listed at p. 144 (station 9923) were collected at this locality. Some of the beds found still farther east are chalky or sandy and contain bluish black chert, in nodules as well as in bands that lie parallel to the bedding. Such beds contain little or no detrital material. At Passe Garde, about 4 kilometers east of Passe Reine, a massive bed of conglomerate about a meter in thickness is interbedded in the limestone. The conglomerate is composed mainly of small rounded pebbles of white limestone, apparently similar to that in the beds below and above it, embedded in a calcareous matrix containing the Foraminifera listed at page 144 (station 9804). White, dense unfossiliferous thin-bedded limestone, interbedded with brownish-gray granular limestone containing pebbles of weathered igneous rock is exposed in a railroad cut on the south side of Rivière d'Ennery, 3 kilometers southeast of Passe Garde. The Foraminifera listed at page 144 (station 9989) were collected from a bed of the granular limestone.

Rather similar limestone covers most of the south slope of Mont Puilboreau, on the road from Ennery to Plaisance. At places the limestone is thin-bedded and contains shaly or sandy beds; at other places it is more massive and contains less detrital material. Thick beds of coarse crystalline limestone rich in upper Eocene Foraminifera (see list, p. 144, stations 9862, 9863, and 9864) were noted at several places on this slope. Some thick but regular beds of coarse conglomerate containing large cobbles of dark igneous rock are also exposed on this slope. About 2 kilometers

A. TYPICAL EXPOSURE OF THIN-BEDDED UPPER EOCENE LIMESTONE IN WESTERN PART OF VALLEY OF RIVIÈRE D'ENNERY.



B. THIN-BEDDED LIMESTONE OF SUPPOSED UPPER EOCENE AGE ON GRANDE RIVIÈRE DU CUL-DE-SAC.

C. CHALKY UPPER EOCENE LIMESTONE CONTAINING BANDS AND NODULES OF CHERT EXPOSED IN SEA CLIFF NEAR SALTROU.

from Ennery, on the lower part of the slope, there is an exposure of solid black basalt, probably part of the underlying basement of igneous rock and doubtless the source from which the cobbles in the conglomerate were derived.

Limestone belonging to the same series crops out southeast of Ennery, along the road to St.-Michel de l'Atalaye, between Ennery and the foot of Crête Salée. Foraminifera were collected from gray granular limestone about a kilometer southeast of Ennery. (See list, p. 144, station 9924.) The basalt underlying the limestone crops out at the foot of a cliff on the south side of Rivière d'Ennery, about 3 kilometers southeast of Ennery. A bed of limestone, 50 centimeters in thickness, above the basalt contains small weathered pebbles of the basalt. The Foraminifera listed at page 144 (station 9925) were collected from this bed. This locality is one of the few at which free tests of upper Eocene Foraminifera were obtained. A massive conglomerate containing cobbles of basalt as large as a man's head embedded in a calcareous matrix overlies the lower bed of limestone. The highest beds exposed consist of thin-bedded white limestone. The beds in this cliff strike N. 45° E. and dip 15° NW. and are broken by a normal fault of small throw that dips steeply southeastward.

The rocks in this region—that is, along Rivière d'Ennery and on the north slope of its valley eastward and westward from Ennery—appear to belong mainly to the thin-bedded type that carries a large amount of detrital material, which is so prominently developed on Morne Biénac and elsewhere in the Montagnes de Terre-Neuve. In all this region the prevailing dip is southward, even somewhat south of the course of Rivière d'Ennery. This dip, although it is doubtless reversed in the region not far beyond, appears to carry the thin-bedded limestone beneath the great mass of limestone that caps the Montagnes Noires to the south and that forms conspicuously black and cliffy slopes. However, this steep front of the Montagnes Noires was not examined, and its exact relations are unknown.

There appears to be some question whether the limestones near Ennery are identical with those of Morne Biénac and others of the same type farther west. The Foraminifera obtained in this region generally more closely resemble those found in the massive and pure type of limestone of the Montagnes de Terre-Neuve, and possibly the beds to the east, near Ennery and beyond, should be correlated with those in the higher part of the series in the Montagnes de Terre-Neuve, although lithologically they rather resemble the beds in the lower part of the series. It can hardly be doubted that the beds bordering the plain near Gonaïves are almost if not identically the same as those of Morne Biénac.

Montagnes Noires.

Northwestern part.—Southeast of the valley of Rivière d'Ennery, in the region between the Artibonite Plain and St.-Michel de l'Atalaye, the

Montagnes Noires consist of ranges composed almost entirely of upper Eocene limestone, generally very pure and usually either thick-bedded or massive, closely resembling the limestone that forms the interior ranges of the Montagnes de Terre-Neuve. The thin-bedded limestones containing detrital beds, which are typically exposed about the borders of the Montagnes de Terre-Neuve and in the valley of Rivière d'Ennery, are almost absent, so far as shown by the examination of the mountain front between Gonaïves and Dessalines and by the traverse of the ranges from Dessalines through Paul to St.-Michel de l'Atalaye. In this region the limestone rests on andesitic volcanic rocks and old argillites, probably of Cretaceous age. The older rocks are exposed about the borders of the mountain ranges and underlie extensive valleys in the interior of the mountains. The contact undoubtedly is unconformable, although no basal conglomerate was found on the weathered and talus-covered contacts. Descriptions of the upper Eocene rocks at different localities follow.

Morne Grammont, although separated by an alluvial plain from the Montagnes Noires, is geologically a part of that province. This mountain appears to be composed mainly if not entirely of upper Eocene limestone of a peculiar type, semmingly identical with that on Morne Bouvard (see p. 120) both lithologically and faunally. This rock is very dark, both on the weathered exterior and on broken surfaces. It is unusually pitted and roughened by solution. In general the fossils are rather sparse, although at certain horizons they are abundant (see list, p. 144, stations 9770 and 9742) and include a peculiar *Orthophragmina,* which is found also on Morne Bouvard. Structurally the mountain appears to form a tilted block that dips northeastward, although no positive dips were obtainable, as the rock appears massive. Similar limestone is exposed on some small hills in the plain east of the mountain and on one of them the limestone rests on dark volcanic rock. Igneous rock probably underlies the limestone of Morne Grammont at the southwest base of the mountain, which was not examined. It seems likely that here, as at Morne Bouvard, this limestone of unusual facies is the equivalent of the lighter colored rocks to the northeast, which contain a somewhat different fauna, particularly as the front range of the Montagnes Noires toward Dessalines appears to contain much dark limestone that indicates a transition between the two types.

The front range of the Montagnes Noires between Dessalines and Gonaïves has a steep slope, which overlooks the Artibonite Plain. The northern half of this slope is peculiarly straight and regular and apparently is a fault scarp. (See p. 336.) It was examined at a locality about 12 kilometers southeast of Gonaïves, where its crest is about 350 meters above sea level and 300 meters above the bordering plain. From the border of the plain up to an altitude of about 200 meters above sea level the slope is composed of volcanic rock, and from that altitude to the summit of gray-

ish limestone, at most places rather white in the interior and apparently massive. It is much pitted and pinnacled by solution. The configuration of the slopes on opposite sides of the range unmistakably indicates that the limestone is tilted to the northeast, for the northeastern slope is long and gentle compared to that facing the plain. Very high mountains of dark limestone rise in a much higher range to the northeast.

Farther southeast, where the road from Gonaïves to Port-au-Prince skirts the base of this range, its front is more irregular and not so steep. The rock exposed in the foothills is limestone, commonly rather dark on broken surfaces. Similar limestone forms the main front range in the gorge of Rivière Coupe-à-l'Inde east of Dessalines, on the trail to St.-Michel de l'Atalaye. In front of this range is a ridge of limestone, perhaps 100 meters high, which was not examined.

Behind the gorge of Rivière Coupe-à-l'Inde lies a valley that is underlain by andesitic rock, and beyond this valley stands a second much higher range, which is composed of limestone that apparently rests on volcanic rock. This range, probably 1,000 meters in height, seems to be composed entirely of pure, white, thick-bedded or massive limestone, from which the fossils from stations 9885, 9886, and 9887 were obtained. (For list see p. 144.) The beds in this range appear to be crumpled into a number of folds of northwesterly trend.

The third and highest range, whose peaks probably rise 1,000 to 1,400 meters above sea level, lies between the valley of Rivière Paul and a similar flat valley to the northeast (Savane Le Cidra), both of which are about 400 meters above sea level. Although the structure in this range and the one just considered is not very well understood, the thickness of limestone in each must be at least 500 to 1,000 meters and perhaps considerably more. In fact, the relations observed at the border of the third range suggest a synclinal structure, but this doubtless is modified by further folding in the interior of the range. The rock probably is mainly pure massive limestone, although outcrops of a thin-bedded white limestone without fossils and suggestive of the upper Eocene on Morne Biénac and in the valley of Rivière d'Ennery were found in the central part of the gap that traverses this range east of Paul. Fosils collected from more massive, brownish beds to the west are listed at page 144 under station 9883.

The fourth and last range, which borders the Central Plain, is lower, rising only about 700 or 800 meters above sea level, and it is also narrower than the other ranges. The rock in the western part of this range appears to be white massive, rather cherty limestone. It yielded the Foraminifera listed opposite page 144 (station 9890). In this range the rocks appear to be tilted steeply, if not actually overturned, as is suggested by apparently southwestward dips at the edge of the plain about 3 kilometers southwest of St.-Michel de l'Atalaye.

The lower part of the southwestern slope of the Montagnes Noires was examined northeast of Savanne-à-Roche on the trail to Perodin. Here

the rock is a white massive or very thick-bedded limestone, presumably of late Eocene age, although no determinable fossils were found in it. The top of what corresponds to the front range in this locality is a wide bench that stands at an altitude of about 700 meters above sea level. Behind it rises a much higher range, the rocks on which, all the way to its crest, appear to be limestone. At this locality the anticlinal arch of the mountains seems to rise much higher than in the area between Dessalines and St.-Michel de l'Atalaye.

Southeastern part.—Along the trail from Mirebalais through Dufailly to Thomonde the main part of the Montagnes Noires forms a single anticlinal range. Thin-bedded limestone, which weathers chalky and contains bands of chert, crops out on the crest of the range and on the slopes near the crest. Foraminifera of upper Eocene age were collected from the limestone and chert. (See list, p. 144, stations 9789 and 9919.)

The single anticlinal ridge known as Morne Michel, extending from the gorge of Rivière Artibonite southeastward to the abandoned gorge followed by the road from Mirebalais to Las Cahobas, was examined only along the southwestern slope near Mirebalais. Dense, brittle white limestone that breaks with a conchoidal fracture crops out on this slope. Float of this limestone, which is unfossiliferous at the outcrops examined, contained the upper Eocene Foraminifera listed at page 144 (station 9456).

The basaltic rocks that underlie the upper Eocene limestone are exposed in the deep gap across the mountains southwest of Las Cahobas. Outcrops of the upper Eocene limestone were not examined at this locality, but Foraminifera of upper Eocene age were collected from float of white limestone that probably comes from the same beds as the large block of massive limestone that stands along the road. (See list, p. 144, station 9903.)

Limestone of upper Eocene age forms the crest of the range at the southeastern end of the Montagnes Noires, but the rocks are not well exposed along the trail from Belladère to Savanette, the only route along which the range was crossed. Most of the rock seems to be thin bedded, and its weathered surfaces have a chalky appearance. Foraminifera were obtained from float at two localities. (See list, p. 144, stations 9914 and 9915.)

Chaîne des Mateux.

The Chaîne des Mateux was examined principally along a trail leading from l'Arcahaie north by east across the central part of the range to Marché Désarmes. In this region the surface rocks on all the higher part of the range, at an altitude of more than 800 or 900 meters above sea level, are of upper Eocene age. These rocks probably rest unconformably on a basement composed mainly of volcanic rocks, but this basement is not exposed along the route traversed. Upon the upper Eocene beds on the flanks of the range, and to all appearances conformably, rests limestone of supposed Oligocene age.

The succession of the upper Eocene rocks was not ascertained very clearly. Beds that probably lie in the lower part of the series are exposed east of the habitation called Couyau on Morne Couyau, a high ridge along the crest of the range. These beds consist partly of rather pure white limestone, gray on weathered surfaces and generally decomposed and soft, like chalk. They contain numerous poor casts of fossils, including corals. The beds are from 15 to 30 centimeters in thickness. Interbedded with this limestone is a considerable amount of gray or brown sandy material that is composed chiefly of very weathered grains of basaltic rock. On soil-covered slopes this material is easily mistaken for weathered basalt. It yielded a foraminifer, probably of upper Eocene age. (See list, p. 144, station 9993.) The presence of these detrital beds, which are absent elsewhere in the upper Eocene of this region, and the anticlinal structure of the range suggest that these are the lowest beds of the series exposed on the route described.

The first ridge northeast of Morne Couyau is but slightly lower and is more rugged. It seems to be composed entirely of upper Eocene limestone that is pure and massive or thick-bedded, white on fresh and gray on weathered surfaces. It is considerably pitted by solution but at places breaks into smooth-weathered blocks. This limestone rather closely resembles the massive upper Eocene limestone of the Montagnes Noires and the Montagnes de Terre-Neuve. At some places it contains many specimens of *Nummulites parvula* Cushman (see list, p. 144, stations 9487 and 9502), as well as indeterminable corals.

On the south slope of Morne Couyau there is white limestone like that just described. Farther southwest, in the vicinity of the habitation Caille-Mare, the limestone is thick-bedded but very cherty, full of large disk-shaped nodules of chert that contain many small undetermined Foraminifera. South of Caille-Mare the limestone is more thin-bedded but contains here and there thick beds of crystalline limestone full of larger Foraminifera (see list, p. 144, station 9486) and suggestive of the fossiliferous beds in the upper Eocene on the south slopes of Mont Puilboreau, near Ennery.

Structurally the Chaîne des Mateux is an anticlinal range, probably the most perfect example found in the Republic. The anticline is modified by secondary folds, and the resulting structure of the upper Eocene beds is a series of broad anticlines and synclines. (See Fig. 5.) On the lower slopes of the major anticline the upper Eocene beds plunge beneath the younger Oligocene and Miocene beds. The observations made afforded no means of estimating the thickness of the upper Eocene beds in this area, but it is certainly hundreds of meters if not perhaps 1,000 or 2,000 meters.

The upper Eocene limestone of the Chaîne des Mateux was seen at a locality about 3 kilometers southeast of Mont Rouis, where the bluffs of

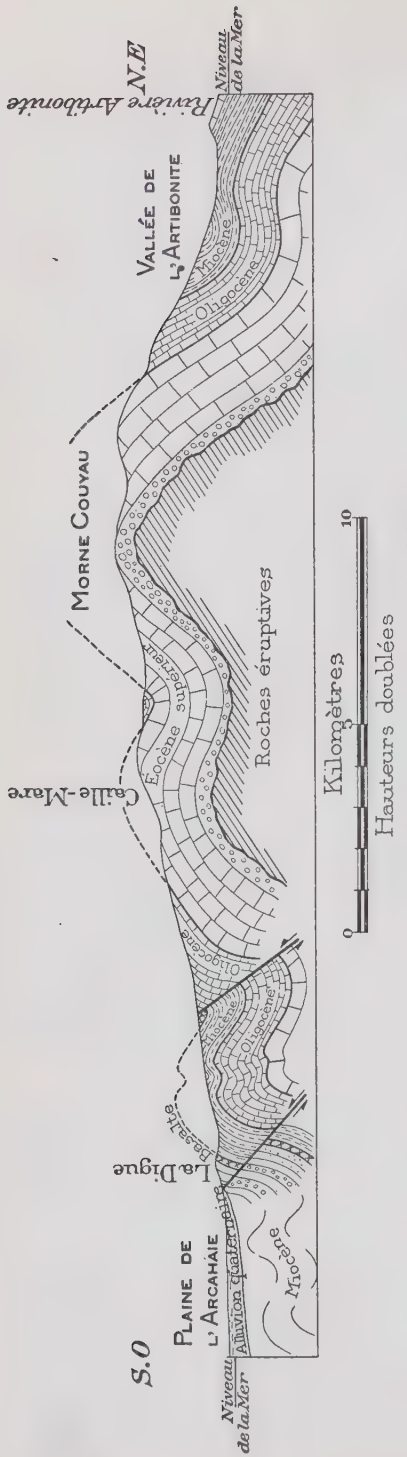


FIGURE 5.—Section across the Chaîne des Mateux.

the mountain range border the sea. From a bluff of pure, white, badly brecciated limestone beside the railroad the fossils listed at page 144 (station 9548) were collected. The Oligocene limestone that borders the range farther to the southeast is missing at this locality, and this relation probably holds around all the northwest termination of the range, for the cliffs and dark slopes of the Hauts de St.-Marc look from a distance like typical upper Eocene limestone.

Along the trail from Saut d'Eau (Ville Bonheur) to Port-au-Prince, at the southeast end of the Chaîne des Mateux, thin-bedded dense limestone crops out on the ridge south of the valley called Fond-des-Orangers. Float probably derived from this limestone contained the upper Eocene Foraminifera listed at page 144 (station 9459).

Montagnes du Trou d'Eau.

Limestone of upper Eocene age seems to be the surface rock in the central part of the western half of the Montagnes du Trou d'Eau, at least along the road from Port-au-Prince to Mirebalais. Most of the rock is massive and gray on weathered surfaces. The south slope of the mountains along the road is covered with talus. Float of hard white limestone collected on the north slope of Morne Terre-Rouge contained numerous specimens of upper Eocene Foraminifera. (See list, p. 144, station 9790.) The succession and thickness of these rocks is not known.

Massif de la Selle.

Limestones of known or supposed upper Eocene age are the most extensive surface sedimentary rocks in the Massif de la Selle. The limestones rest on an eroded surface of basalt, but the lower part of the series was seen at only a few localities. The contact between the basalt and the overlying limestone is exposed on the south coast just west of the small stream at the habitation called Adieu-au-Monde (or Guillaumone), in the eastern part of the arrondissement of Jacmel. Here massive limestone rests on an irregular eroded surface of basalt, although no basal conglomerate was noted. Beds at the base of the series of upper Eocene limestones are well exposed on Rivière Gosseline, along the trail from Jacmel across the mountains to Carrefour. They consist almost entirely of detrital material and are made up of shale, sandstone, conglomerate, and sandy limestone. A layer of sandy limestone half a meter thick contained carbonized plant fragments and an undetermined species of *Cornuspira*. Basalt crops out a short distance farther upstream, but the contact was not seen. (See Fig. 6.) Similar detrital rocks and dark impure limestones occur in the same stratigraphic position on the Grande Rivière de Jacmel, on the trail from Jacmel to Léogane. They are

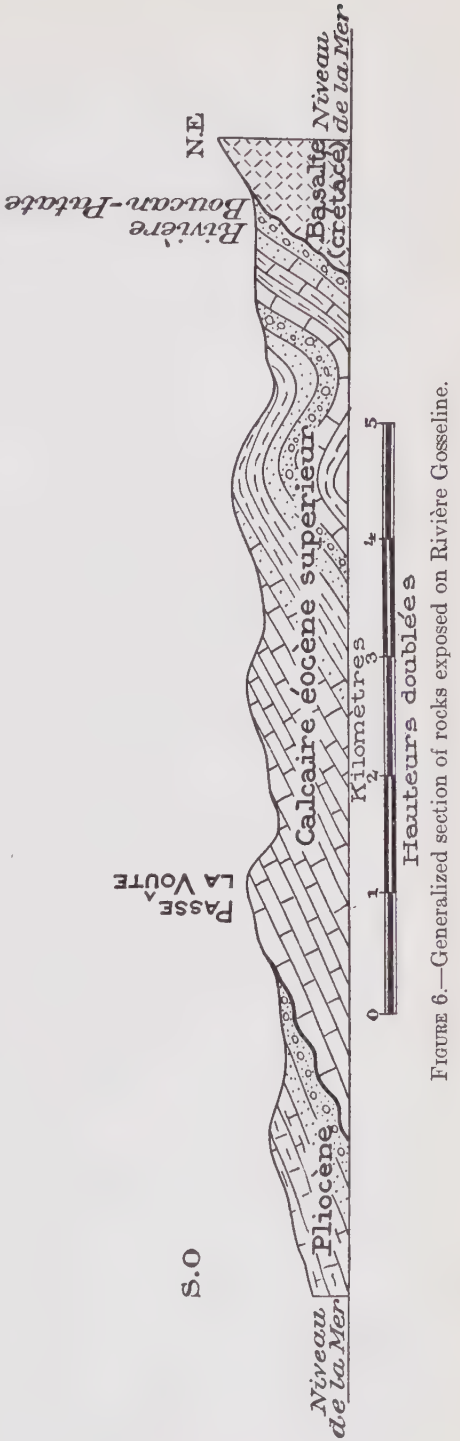


FIGURE 6.—Generalized section of rocks exposed on Rivière Gosseline.

more fully described on page 476, in the matter on deposits of manganese minerals.

Above these basal beds the upper Eocene limestone resembles rock of the same age in other parts of the Republic and consists of two principal types—thin-bedded limestone, dense or chalky on weathered surfaces and in most places containing nodules and bands of chert parallel to the bedding, and massive limestone that at many localities forms a solution breccia.

The highest beds on the north slope were examined on the Grande Rivière du Cul-de-Sac. Both above and below the narrow gorge above Bassin Général the limestone occurs in thin even beds from 3 to 10 centimeters in thickness. (See Pl. XII, *B*.) The narrow gorge is due to steep slopes in lower massive limestone on the north flank of an anticlinal arch. The thin-bedded limestone is crumpled and ruptured along small high-angle thrust faults.

Similar limestones crop out on Morne Hôpital, the conspicuous ridge south of Port-au-Prince. The rock is typically gray on weathered surfaces and white on freshly broken surfaces and is considerably pitted and roughened by solution. Much of it is massive or rather thick-bedded, but there is considerable variation, and in some localities the beds are regular and not more than 10 or 15 centimeters thick. The rock of a few beds is soft and chalky rather than dense and fine-grained. The limestone contains some chert, but it is nowhere abundant. The relation of this limestone to the water supply of Port-au-Prince is discussed on page 570. These upper Eocene limestones dip northward rather steeply, but the folding is complex in detail and is modified by many small thrust faults that result from the breaking of overturned folds. Such structure is well exhibited in the first deep ravine east of Pétionville, near Source Millet. The folds here are overturned to the north.

Thin-bedded limestone is exposed on Rivière Froide, west of Port-au-Prince. Farther west, along the main road that connects Port-au-Prince and Léogane, in the region between the villages of Carrefour and Gressier, there are a number of road cuts in which supposed upper Eocene limestone is exposed. At all these exposures the rock is notably thin-bedded, the beds ranging generally from 3 to 10 centimeters in thickness. The rock is a white limestone, usually rather soft and chalky where weathered. The beds are nearly everywhere steeply tilted in different directions and thrust faults are associated with the crumpling.

Similar dense thin-bedded limestone forms the surface rock along virtually the entire distance between Pétionville and Kenscoff, as seen along the trail. In the southern part of this region the beds apparently are arched into broad, rather open anticlines, which are separated by similar synclines. (See Fig. 21, page 335.) Farther north, near the edge of the mountain, the beds are more sharply folded and the folds are overturned to the north, some of them being broken along thrust faults. A thickness

of at least 500 meters of these thin-bedded limestones is exposed on the steep mountain slope south of Rendez-vous, where the beds dip southward with an average dip of 30°, but the total thickness is probably several hundred meters more. Northeast of Furcy more massive lower beds are silicified along the fault between the limestone and basalt.

The only significant fossils found in this whole series of limestones south and southeast of Port-au-Prince are the Foraminifera that were collected near Kenscoff and on the crest of Morne Hôpital (see list p. 144, stations 9587 and 9553, respectively), from beds near the middle of the section. The Foraminifera that were obtained from the higher beds (see list, p. 144, stations 9608, 9443, 9583, 9585) have no stratigraphic significance, and these beds may be of lower Oligocene age.

Limestones, all presumably of upper Eocene age, are the only rocks seen in crossing the mountains from the Cul-de-Sac Plain to the south coast, along the trail from Fond-Parisien through Fond-Verrettes to Grand-Gosier, near the Dominican border. In the first exposures, a few kilometers south of Fond-Parisien, the rock is gray and massive on the weathered ledges and yielded an indeterminate species of *Stylophora* (station 9505). The same kind of massive limestone crops out where the trail reaches a stream northwest of Fond-Verrettes. Near the spring that feeds the right branch of this stream the massive limestone forms a solution breccia. Near Fond-Verrettes crumpled thin-bedded limestone is interbedded with massive limestone. Thin-bedded limestone crops out at several places along the north slope of the main central range. On the crest of the central range, which has an altitude of 1,700 meters above sea level, the rocks are obscured by a thick mantle of red clay. An *Operculina* similar to *O. ocalana* Cushman was collected from a pinnacle of massive limestone that projects above the clay on the south slope not far from the crest (station 9594). Typical upper Eocene Foraminifera, similar to those in the massive limestone of the northern part of the Republic, were collected farther down the south slope from a ledge of jagged solution-pitted limestone. (See list, p. 144, station 9596.)

All along the south coast from the Dominican border westward to Jacmel the most common type of upper Eocene rock is white limestone in thin, even beds from 2 to 20 centimeters thick. This limestone contains chert in nodules and in bands that lie parallel to the bedding planes. The thickness of the bands ranges from a few centimeters to almost a meter. Some of the beds of limestone are hard and dense; other beds are dazzling white and chalky on the weathered surface; and still others consist of granular limestone. Good exposures of this thin-bedded limestone may be seen at many localities, particularly along Rivière Pédernales on the trail from Grand Gosier to Anse-à-Pitre. The first high sea cliff northwest of Grand-Gosier, which is 200 meters high, is composed from top to bottom of thin-bedded hard white limestone, which weathers chalky and which contains a few lenses of chert. The beds in this cliff are broken by faults.

In Plate XII, *C*, is given a view of the first sea cliff west of Saltrou, showing the thin-bedded limestone that weathers chalky and that contains nodules and bands of chert. Upper Eocene Foraminifera were collected at several localities but only from beds of granular limestone. (See list, p. 144, stations 9510, 9511, 9444, 9513, 9600.)

Similar thin-bedded limestone that weathers chalky forms the upper part of the upper Eocene series of rocks on Rivière Gosseline. Numerous specimens of a small stellate *Orthophragmina* were collected at Passe la Voûte, the fourth crossing of the river as one goes from Jacmel to Carrefour (station 9605). Farther upstream the lower beds described on page 129 crop out. (See Fig. 6.)

A conspicuous massive limestone, which usually forms a typical solution breccia, crops out in the desolate rock-floored plain at Anse-à-Pitre at the Dominican border and in the ridge west of the plain. The rock is stained light red or even blood-red by recemented clay. Its surface is deeply pitted and it makes curiously shaped pinnacles. This rock forms the cliffs marked " red cliffs " on chart No. 2653 of the Hydrographic Office of the United States Navy. From a distance it could easily be mistaken for a scoriaceous lava. The stratigraphic relations of this limestone to the thin-bedded limestone are not precisely known, but it probably lies higher in the section. The two kinds of limestone seem to be in fault contact in a bluff on the right bank of Rivière Pédernales, about 3 kilometers north of Anse-à-Pitre, but the thin-bedded limestone may dip under the massive limestone, as the lower slope of the bluff is covered with talus.

In the first high sea cliff southeast of Grand-Gosier, about half a kilometer from the village, the thin-bedded limestone is crumpled, and toward the east end of the cliff a breccia of massive limestone containing angular pieces of the thin-bedded limestone and chert rests on an irregular surface that truncates the bedding. It is not known whether this breccia has any structural significance.

Massif de la Hotte.

The most widespread series of rocks in the Massif de la Hotte is of known or assumed upper Eocene age and here as elsewhere it consists mainly of limestone. This series rests unconformably on a basement composed mainly of dark basaltic rocks and in minor part of older limestones and metamorphic rocks. Rocks of Oligocene age were not recognized, although some of the limestones here grouped in the upper Eocene may really be of Oligocene age.

At the base of the upper Eocene there is commonly a considerable thickness of conglomeratic or sandy beds composed mainly of basaltic débris, in many places difficult to distinguish from weathered igneous rock but generally interstratified with impure, dark, shaly limestone beds and so far as observed almost unfossiliferous. No good sections of these beds were obtained, but they probably form a series that reaches a thickness of a few hundred meters at some localities and at other localities is very

thin. A number of exposures of beds believed to be basal upper Eocene are described below.

North of the road on the east side of Pont de Miragoâne basaltic sandstones and conglomerate are interbedded with very dark or black rock that is probably a very impure limestone. These beds dip northward toward the base of Tapion de Miragoâne, where higher and purer limestone crops out.

At the east end of the Asile Valley, about 4 kilometers from Asile, a detrital basaltic rock underlies a high bluff of supposed upper Eocene limestone. Other exposures of beds at the base of the limestone were seen along the trail between Aquin and the Asile Valley. The beds consist of dark-brown impure limestone containing detrital material that is probably derived from basalt.

The basal conglomerate of the limestone is exposed on the trail from Cavaillon to St.-Louis du Sud, about 5 kilometers east of Cavaillon. It contains small pebbles of weathered basalt and dark limestone in a calcareous matrix. The outcrop of the conglomerate was traced to a point within a distance of a few meters of an exposure of weathered basalt. Beds of shale and shaly dark limestone overlie the conglomerate. A road-cut 8 or 9 kilometers west of Aquin exposes basalt overlain by brownish and greenish shale and impure shaly limestone.

Similar beds, which are believed to lie near the base of the upper Eocene limestone, are exposed for about a kilometer along the trail between Les Cayes and Port-Salut on the eastern slope of the Port-Salut Peninsula. The beds consist partly of rather hard blue or gray marl and partly of interbedded shale and impure limestone. They are sharply folded and their strike and dip vary within short distances. These beds are overlain by white limestone of the thin-bedded and rather cherty type, of supposed upper Eocene age. The volcanic rocks that presumably underlie the basal beds are not exposed along the trail.

Other beds very much like those just described were found about 4 or 5 kilometers north of the Sources Chaudes de Dame-Marie or de Jérémie, where unfossiliferous gray sandy beds overlie dark limestone. In the same locality, just at the bed of the Bras-à-Gauche, is a bluff of dark sandy and shaly limestone, very hard, partly thin-bedded and partly thick-bedded. Rounded nodules break out of certain beds. Carbonized plant remains are rather abundant in the rock. This whole series is probably basal upper Eocene, for the underlying basalt crops out a short distance to the south in the river bed.

At the cemetery just south of the town of Anse d'Hainault beds that probably lie near the base of the upper Eocene form a prominent ridge. They are thin-bedded shaly or fine, sandy, dark-gray calcareous sediments, which break with conchoidal fracture. The thickness of the exposed beds must be from 100 to 200 meters if not more. The beds appear to overlie basalt and dip steeply northward.

Certain beds of marl and conglomerate east of Baradères, described as of questionable Miocene age on page 225, are possibly basal upper Eocene. If so, the limestone in the conglomerate must be derived from older, probably Cretaceous, limestone that underlies the basalt.

The remaining and principal part of the upper Eocene section in the Massif de la Hotte may be classified into two types of limestone: (1) white thin-bedded limestone, generally dense but here and there open-textured and chalky, usually breaking with conchoidal fracture, most of it more or less cherty and some of it extremely so, in few places containing determinable fossils but rarely rich in orbitoid Foraminifera; (2) massive or thick-bedded white limestone, in some places crystalline, weathering gray and to pitted forms, at many places full of small undetermined Foraminifera but at a few containing large Foraminifera. The second type closely resembles the massive upper Eocene limestone in the northern part of the Republic. It yields a characteristic red ocherous soil and in many places forms a solution breccia.

Cherty limestone was found north of Pont de Miragoâne in association with impure basal beds, and it also occurs abundantly as float farther north, at the base of the escarpment of Tapion de Miragoâne, which appears to be composed mainly of the massive type of limestone.

Most of the limestone on the road between Miragoâne and Aquin, in the interior of the peninsula, is of the thin-bedded type containing chert, float of which furnished the upper Eocene Foraminifera listed at page 144 (station 9518).

At the south border of the first mountain range south of Anse-à-Veau chert makes up virtually the entire section of supposed upper Eocene beds. It is so black that it has been mistaken for coal. The chert beds here are uncommonly thick, in some places 30 centimeters in thickness. On the north side of the range white limestone, probably thick-bedded, constitutes the main part of the section. In the second range between Anse-à-Veau and l'Asile much similar float of dark chert is associated with white limestone, probably of upper Eocene age, but no good exposures were noted.

Cherty white limestone was found on the first slope southeast of Roseaux, but its relations were not determined. Southwest of Jérémie, at and near Moron, thin-bedded cherty limestone is very abundant and appears to dip northward beneath more massive purer limestone.

East of Dame-Marie, on the trail to Montagnac, white limestone with chert is very abundant and yielded upper Eocene Foraminifera. (See list, p. 144, station 9629.) The beds here are from 10 to 20 centimeters thick—somewhat thicker than elsewhere. Very similar cherty limestone is abundant south of Dame-Marie on the ridge just north of Bariadèle and contains abundant upper Eocene Foraminifera (see list, p. 144; stations 9631, 9632.) This cherty limestone is suspected to be in the lower part of the upper Eocene series. The chert in this region is lighter colored than that near Anse-à-Veau and generally is slightly bluish.

Most of the limestone exposed along the south coast from Port-Salut to Jacmel is white and thin-bedded, commonly dense and in places porous or chalky, has a splintery conchoidal fracture, and contains more or less chert. It is quite devoid of large fossils, although at some localities it contains abundant *Globigerina* and other minute Foraminifera. This rock forms the plateau of the Port-Salut Peninsula, where it lies nearly horizontal and rests on the impure, probably basal beds described on page 133. On the east slope of the peninsula the beds plunge steeply beneath the Cayes Plain, if indeed they are not broken by a fault along that side. Beds almost identical in appearance and also nearly horizontal compose the ridge between the Cayes Plain and Cavaillon and were recognized between Cavaillon and St.-Louis du Sud, where they overlie the impure transition beds described on page 133, which rest on the basalt.

On the east side of Aquin Bay the trail from Aquin to Côtes-de-Fer crosses low hills composed of limestone in beds 20 to 30 centimeters thick. This limestone is gray and chalky on weathered surfaces and contains bands of chert. Along the coast the upper Eocene rocks are generally concealed by Quaternary deposits. Chalky limestone of assumed upper Eocene age crops out in a ravine north of Cap Raymond, on the trail between Mayette and Bainet. Farther east, between Bainet and Jacmel, white granular limestone with chalky weathered surfaces is exposed on l'Eau Gênée, west of Morne Fontai. Foraminifera similar to those in the granular limestone farther east were collected from similar limestone on the west slope of Morne Fontai. (See list, p. 144, station 9649.)

It therefore seems that thin-bedded cherty and chiefly unfossiliferous limestone is characteristic of the lower part of the upper Eocene section over virtually all the Massif de la Hotte and lies in normal succession above the more impure basal beds. It is quite possible, however, that cherty beds occur in the higher part of the section at some places, and this criterion should be used with caution.

The thickness of the upper part of the upper Eocene section is not known but probably aggregates some hundreds of meters. On the Port Salut Peninsula and between Les Cayes and Cavaillon the thickness can not much exceed 300 meters, as the beds lie nearly flat and the relief would not allow for a greater thickness above the basal beds.

The massive or thick-bedded purer type of limestone covers large areas in and around the section called Plymouth, southeast of Jérémie, and is exposed along the trail to Jérémie most of the way from Petit-Trou de Nippes to Roseaux. A small species of *Nummulites,* similar to one found in upper Eocene rocks of other parts of the Republic, was collected from this limestone between Petit-Trou de Nippes and Baradères (station 9547). This limestone is also found in part of the first range south of Jérémie and at places in the succeeding ranges to the south and is well developed near Montagnac east of Dame-Marie. Similar limestone appears to constitute the mass of the first range north of Port-à-Piment,

the range south of Camp Perrin (station 9509, see list, p. 144), and the heights of the range south of the Asile Valley.

Massive limestone is found near Miragoâne (see Pl. XL, *B*) and probably forms most of Tapion de Miragoâne. On the road leading eastward from Miragoâne, about half a kilometer from the town, the small *Dictyoconus,* which is very abundant in uper Eocene rocks of the northern part of the Republic, was collected from this massive solution-pitted limestone (station 9517). West of the locality where the Aquin road branches off the limestone is faulted against basalt.

This limestone appears generally to overlie the thinner bedded and cherty limestones, but at some localities it probably rests directly on the dark impure basal beds, as for instance along the trail between Aquin and l'Asile. Thus either the upper beds are transgressive with overlap or at places the thin-bedded limestone passes by lateral gradation into more massive and less cherty rock.

Along the south coast between Mayette and Jacmel massive limestone overlies the thin-bedded chalky limestone. At some localities it seems to dip more gently than the thin-bedded limestone, but it probably is the same massive limestone that elsewhere is known to be of upper Eocene age, although it may be Oligocene or Miocene. No fossils were found in it except poorly preserved indeterminate corals. This massive limestone yields a heavy residue of red clay that is much more fertile than the light-colored soil formed by the thin-bedded limestone.

The structural features of the upper Eocene rocks of the Massif de la Hotte were not very clearly ascertained, but in its western part they appear to be generally folded into sharp, open folds that trend more or less nearly east and west. The general features are apparent in Figure 7, a section across the north side of the massif from Jérémie to the Sources Chaudes. Although not accurate in detail, this section gives the general features of the structure. An exception to the general folded structure is found on the south coast, where the thin-bedded cherty limestones of the Port-Salut Peninsula lie nearly horizontal.

Faulting also has taken place on a considerable scale, although generally it is not easily recognized. Topographic and stratigraphic evidence indicate that thrust faults of considerable magnitude exist at the north side of the Miocene area southwest of Jérémie (see Fig. 7) and at the south side of the lowland near Camp Perrin. (See pp. 235-236 and Fig. 17.) A fault probably borders the south side of the Asile Valley. All these faults are of post-Miocene age. A normal fault is exposed about 1 kilometer southeast of Miragoâne, on the Port-au-Prince road. Massive upper Eocene limestone has been dropped down against the older volcanic rocks. A weathered brecciated zone 3 or 4 meters wide in the volcanic rock marks the fault plane.

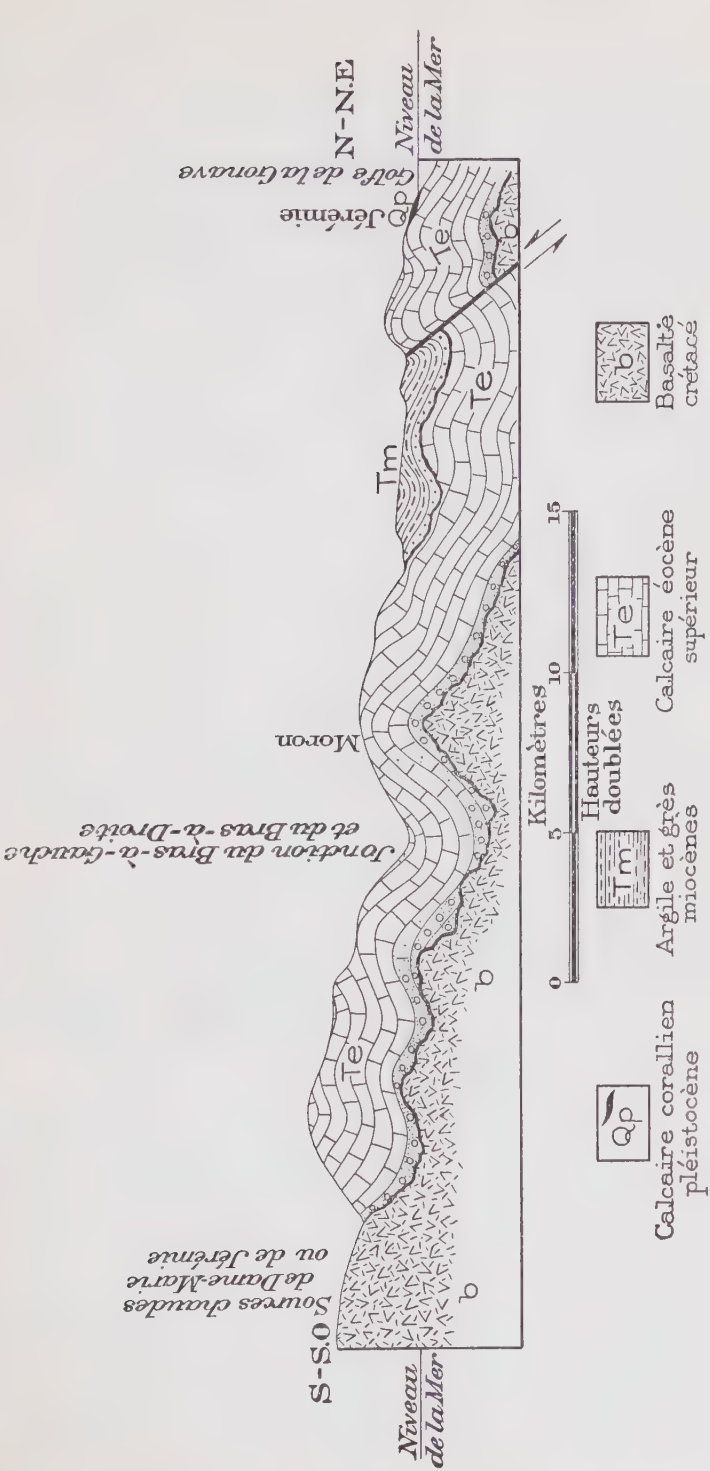


FIGURE 7.—Section across the northwest part of the Massif de la Hotte.

Gonave Island.

Limestones of upper Eocene age cover a large part of the southeastern half of Gonave Island. They are made up of a lower part consisting of thin-bedded limestone having a chalky appearance on weathered surfaces and an upper part consisting of massive limestone. (See Fig. 8.) The greater solubility of the massive limestone has a marked effect on the surface features and on the supply of water. The maximum exposed thickness of the lower chalky limestone is about 100 meters, but its base was not seen. The upper massive limestone is probably several hundred meters thick.

Chalky limestone crops out in the ravine southwest of Anse-à-Galets at and below the spring that supplies this part of the island with water. Here the limestone is rather thick-bedded, but it includes thinner beds of harder, denser limestone, less than 30 centimeters thick. The beds

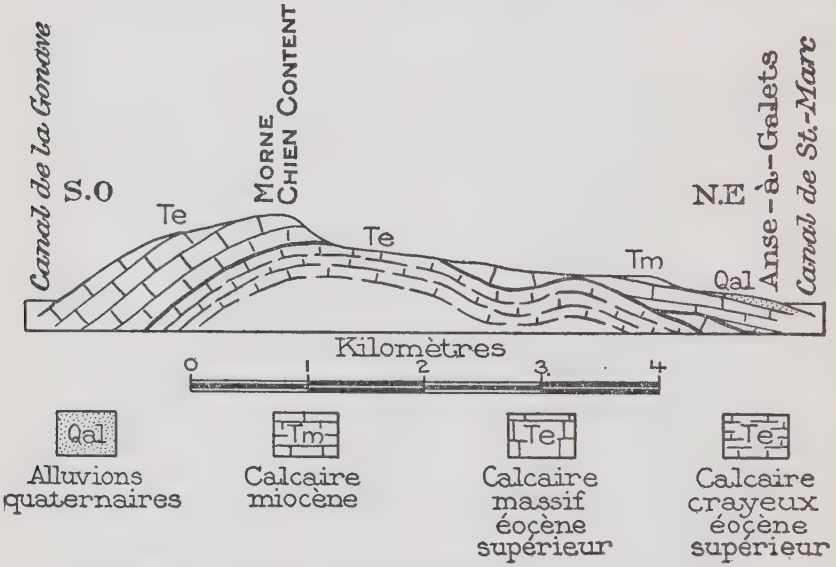


FIGURE 8.—Section across the southeast part of Gonave Island.

probably crop out on the crest of a low arch, but at the spring they dip gently northeastward and farther downstream they dip under massive limestone. Similar chalky limestone is poorly exposed in the ravine northwest of Picmi. It covers a large area west and northwest of the Mapoux Plain and probably underlies the covering of soil in the Mapoux Plain.

The overlying massive limestone forms the ridge along the south coast and apparently covers most of the southeastern end of the island southeast of Fond-l'Aurore. Foraminifera are very abundant in it at some localities (see list, p. 144, stations 9682, 9669, 9670, 9668, 9665, 9681, 9671, 9672, and 9674), and a number of mollusks were collected at the west end of the Mapoux Plain. (See list at p. 144, station 9673.)

Fossils.

Foraminifera are the most abundant fossils in the upper Eocene limestone, as is shown by the list at page 144, which records Foraminifera definitely of upper Eocene age from 75 localities. Faunules from 16 additional localities are added, either because they come from beds that contain significant upper Eocene fossils elsewhere or because the beds are supposed to be upper Eocene. Although the maximum thickness of upper Eocene rocks is very great (between 1,000 and 2,000 meters) it has been impossible to discriminate faunal zones because of the lack of detailed work.

Early workers in other West Indian islands have assumed that similar limestones are deep-water deposits, but the living Foraminifera that are most similar to the fossils obtained are tropical shoal-water species. The almost complete absence of other groups of organisms at many localities is difficult to explain.

Some of the characteristic upper Eocene Foraminifera are shown on Plate XIII. Orbitoidal Foraminifera of the genus *Orthophragmina* are very common in these deposits. So far as known this genus is restricted to rocks of Eocene age in the West Indies and regions near by, although it is found in upper Cretaceous deposits (Danian). In the northern part of the Republic many of the species are identical with or very similar to the following species described by Cushman[1] from rocks of the same age in Cuba: *Orthophragmina cubensis, O. crassa, O. sculpturata,* and *O. pustulata.* Another species, which has been obtained from upper Eocene deposits of the southeastern United States, *O. flintensis* Cushman, is common in nearly all the regions where collections were made.

Species of *Lepidocyclina* are not so widespread nor so abundant as *Orthophragmina.* The association of *Orthophragmina* and *Lepidocyclina* is a characteristic faunal feature of upper Eocene rocks of the West Indies and regions near by, and also of those of Italy and other areas in the Mediterranean region.

Dictyoconus puilboreauensis nannoides Woodring (see p. 609 and Pl. XIII, *B, C*) is the most common foraminifer in the northern part of the Republic. It is very similar to the Plaisance subspecies *D. puilboreauensis puilboreauensis* Woodring.

Species of *Nummulites* and *Operculina,* though abundant, are difficult to determine because most of them are known only from natural rock sections or thin sections.

Poorly preserved corals, which have virtually no stratigraphic significance, were collected at only three localities.

Mollusks are not very abundant in the upper Eocene rocks. The largest collection, 9 or 10 species, represented by casts and impressions, was collected on Gonave Island, at the west end of the inclosed valley called

[1] Cushman, J. A., Carnegie Inst. Washington Pub. 291, pp. 52-55, pls. 9, 10, 15, 1919.

Plaine des Mapoux. No Foraminifera were obtained at this locality. The *Terebellum* is very similar to an unnamed species in the collections of the United States National Museum from a locality near Port Antonio, Jamaica. At the present time this genus is confined to the Indo-Pacific region, but during Tertiary time it lived in all parts of the equatorial geosyncline. Other mollusks from this locality are similar to species from the Ocala limestone of Florida.

Limestones of upper Eocene age which contain the same or a similar fauna are widely distributed in the West Indian region and in adjoining parts of Central and South America.[1] The St. Bartholomew limestone of the island of St. Bartholomew is considered the type of this horizon.

Stations—Upper Eocene.

9854 (B 239 F). Arrondissement of Cap-Haïtien, trail leading up Morne Lorry, west of Cap-Haïtien, about halfway up mountain. J. S. Brown, collector. February 18, 1921.

9853 (B 237 F). Arrondissement of Cap-Haïtien, float on hill slope just north of Carenge at north end of Cap-Haïtien. J. S. Brown, collector. February 18, 1921.

9847 (B 242 F). Arrondissement of Cap-Haïtien, Source Cinq Carreaux, Cap-Haïtien water supply. J. S. Brown, collector. February 19, 1921.

9798 (B 243 F). Arrondissement of Cap-Haïtien, Fort Picolet lighthouse, about 3 kilometers northeast of Cap-Haïtien. J. S. Brown, collector. February 20, 1921.

9744 (B 314 F). Arrondissement of Cap-Haïtien, float on trail from Milot to Citadelle of Christophe, northeast slope of Bonnet-à-l'Évêque, about 5 kilometers south of Milot. J. S. Brown and W. P. Woodring, collectors. March 20, 1921.

9797 (B 294 F). Arrondissement of Cap-Haïtien, from masonry of Citadelle of Christophe. J. S. Brown, collector. March 8, 1921.

9769 (W 306 F). Arrondissement of Borgne, trail from Le Borgne to Port Margot, about 3 kilometers southeast of Le Borgne, west side of Baie de la Rivière Salée. W. P. Woodring, collector. February 23, 1921.

9862 (B 268 F). Arrondissement of Gonaïves, road from Plaisance to Ennery, just south of crest of Mont Puilboreau. J. S. Brown, collector. February 25, 1921.

9863 (B 269 F). Arrondissement of Gonaïves, road from Plaisance to Ennery, south slope of Mont Puilboreau, altitude 690 meters above sea level. J. S. Brown, collector. February 25, 1921.

9864 (B 270 F). Arrondissement of Gonaïves, road from Plaisance to Ennery, south slope of Mont Puilboreau, altitude 585 meters above sea level. J. S. Brown, collector. February 25, 1921.

9924 (W 228 F). Arrondissement of Gonaïves, road from Ennery to St.-Michel de l'Atalaye, 1 kilometer southeast of Ennery, altitude 380 meters above sea level. W. P. Woodring, collector. January 24, 1921.

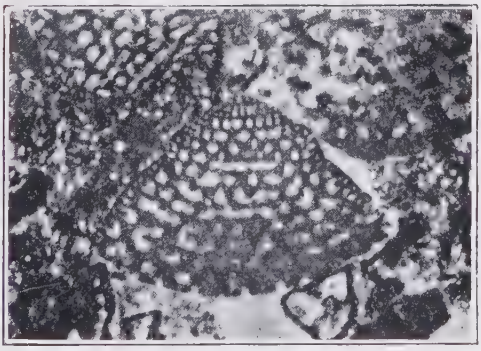
9925 (W 229 F). Arrondissement of Gonaïves, road from Ennery to St.-Michel de l'Atalaye, cliff on left bank of Rivière d'Ennery about 3 kilometers southeast of Ennery. W. P. Woodring, collector. January 24, 1921.

9989 (W 227 F). Arrondissement of Gonaïves, railroad from Gonaïves to Ennery, cut 3 kilometers east of Passe Garde. W. P. Woodring, collector. January 24, 1921.

[1] For a recent summary of the Tertiary deposits of the West Indies and adjoining regions see Vaughan, T. W., Correlation of the Tertiary formations of Central America and the West Indies: Bernice P. Bishop Mus. Special Pub. 7, pp. 819-844, 1921.

A.

B.



C.

SOME CHARACTERISTIC UPPER EOCENE FORAMINIFERA.

A. Orthophragmina crassa Cushman. Vertical sections, ×20. U. S. G. S. station 9854.
B, C. Dictyoconus puilboreauensis nannoides Woodring (p. 609).
B. Horizontal section near base, ×20. U. S. G. S. station 9821.
C. Vertical section, type, ×20. U. S. G. S. station 9821. U. S. N. M. catalogue No. 350588.

9923 (W 226 F). Arrondissement of Gonaïves, railroad from Gonaïves to Ennery, cut about 4 kilometers northeast of Les Poteaux. W. P. Woodring, collector. January 24, 1921.

9804 (B 146 F). Arrondissement of Gonaïves, railroad from Gonaïves to Ennery, cut 27 kilometers from Gonaïves and 4 kilometers east of Passe Reine. J. S. Brown, collector. January 6, 1921.

9868 (B 276 F). Arrondissement of Gonaïves, Morne Macat, west of road from Gonaïves to Gros-Morne, about halfway between the two towns. Float at summit of hill. J. S. Brown, collector. March 2, 1921.

9869 (B 277 F). Arrondissement of Gonaïves, Morne Macat, a short distance northeast of 9868. Float at summit of hill. J. S. Brown, collector. March 2, 1921.

9870 (B 278 F). Arrondissement of Gonaïves, Morne Macat, a short distance northeast of 9869. Float at summit of hill. J. S. Brown, collector. March 2, 1921.

9827 (B 192 F). Arrondissement of Gonaïves, trail from Gonaïves to Terre-Neuve, about a kilometer southeast of Figuier. J. S. Brown, collector. January 21, 1921.

9735 (B 221 F). Arrondissement of Gonaïves, north slope of Morne Blanc near crest, small mountain on coast west of Gonaïves. J. S. Brown, collector. February 11, 1921.

9848 (B 216 F). Arrondissement of Gonaïves, southwest slope of Morne Biénac, about 2 kilometers north of Gonaïves. J. S. Brown, collector. February 8, 1921.

9850 (B 219 F). Arrondissement of Gonaïves, float on crest of Morne Biénac. J. S. Brown, collector. February 8, 1921.

9851 (B 220 F). Arrondissement of Gonaïves, about halfway up southwest slope of Morne Biénac. J. S. Brown, collector. February 8, 1921.

9737 (B 227 F). Arrondissement of Gonaïves, trail from Gonaïves to La Pierre, float at east base of Morne la Pierre. J. S. Brown, collector. February 11, 1921.

9865 (B 273 F). Arrondissement of Gonaïves, near coast between Gonaïves and Anse Rouge, float on crest of Morne Bouvard at Pointe Coridon, altitude 180 meters above sea level. J. S. Brown, collector. February 27, 1921.

9866 (B 274 F). Arrondissement of Gonaïves, float on crest of Morne Bouvard, a short distance east of 9865, altitude 260 meters above sea level. J. S. Brown, collector. February 27, 1921.

9867 (B 275 F). Arrondissement of Gonaïves, float on crest of Morne Bouvard, a short distance east of 9866, altitude 300 meters above sea level. J. S. Brown, collector. February 27, 1921.

9813 (B 163 F). Arrondissement of Gonaïves, Terre-Neuve Valley, float east of Germinie. J. S. Brown, collector. January 12, 1921.

9814 (B 167 F). Arrondissement of Gonaïves, Terre-Neuve Valley, float on trail to Raboteau, about a kilometer north of habitation Gaillardé. J. S. Brown, collector. January 14, 1921.

9824 (B 184 F). Arrondissement of Gonaïves, trail from Terre-Neuve to Philippe, north slope of Morne Songé, about 5 kilometers southeast of Philippe and 7 or 8 kilometers northwest of Terre-Neuve. J. S. Brown, collector. January, 18, 1921.

9800 (K 204 F). Arrondissement of Gonaïves, Terre-Neuve region, southeast of Rocher toward foot of Morne Miguinda. W. S. Burbank, collector. March 28, 1921.

9891 (B 337 F.) Arrondissement of Gonaïves, trail from Gros-Morne to Terre-Neuve, foot of mountains near Savanne Moulin, Section Moulin. J. S. Brown, collector. March 27, 1921.

9821 (B 180 F). Arrondissement of Gonaïves, cliff about a kilometer south of Dolan, near trail from Terre-Neuve to Gonaïves. J. S. Brown, collector. January 17, 1921.

9816 (B 170 F). Arrondissement of Gonaïves, float on mountain slope northeast of Memé, just above large prospect excavation on east side of valley. J. S. Brown, collector. January 15, 1921.

9825 (B 190 F). Arrondissement of Gonaïves, trail from Terre-Neuve to Anse Rouge, gorge about 7 kilometers northwest of Terre-Neuve and 4 kilometers east of Source Marianne. J. S. Brown, collector. January 19, 1921.

9826 (B 191 F). Arrondissement of Gonaïves, trail from Terre-Neuve to Anse Rouge, about a kilometer east of 9825. J. S. Brown, collector. January 19, 1921.

9828 (B 194 F). Arrondissement of Gonaïves, trail from Terre-Neuve to Anse Rouge, about 2 kilometers southwest of Source Marianne, just north of Troupaux. J. S. Brown, collector. January 25, 1921.

9845 (B 212 F). Arrondissement of Môle St.-Nicolas, trail from Jean Rabel to Anse Rouge, Rivière Cadet, about 5 kilometers southwest of Jean Rabel. J. S. Brown, collector. February 2, 1921.

9842 (B 210a F). Arrondissement of Môle St.-Nicolas, trail from Jean Rabel to Anse Rouge, Rivière Cadet, about 5.5 kilometers southwest of Jean Rabel. J. S. Brown, collector. February 2, 1921.

9843 (B 211 F). Arrondissement of Môle St.-Nicolas, trail from Jean Rabel to Anse Rouge, Rivière Cadet, about 6 kilometers southwest of Jean Rabel, near contact of limestone and volcanic rocks. J. S. Brown, collector. February 2, 1921.

9795 (K 120 F). Arrondissement of Môle St.-Nicolas, trail from Jean Rabel to Anse Rouge, Rivière Cadet, about 6.5 kilometers southwest of Jean Rabel, from limestone overlying volcanic rocks. W. S. Burbank, collector. February 2, 1921.

9796 (K 121 F). Arrondissement of Môle St-Nicolas, trail from Jean Rabel to Anse Rouge, about 7 kilometers southwest of Jean Rabel. W. S. Burbank, collector. February 3, 1921.

9964 (K 123 F). Arrondissement of Môle St.-Nicolas, trail from Jean Rabel to Anse Rouge, float about 12 kilometers south of Jean Rabel. W. S. Burbank, collector. February 3, 1921.

9742 (B 231 F). Arrondissement of Gonaïves, north end of Morne Grammont, about 5 kilometers southeast of Gonaïves. J. S. Brown, collector. February 12, 1921.

9770 (B 229 F). Arrondissement of Gonaïves, east slope of Morne Grammont, about halfway to crest. J. S. Brown, collector. February 12, 1921.

9890 (B 327 F). Arrondissement of Marmelade, trail from St.-Michel de l'Atalaye to Dessalines, about 3 kilometers southwest of St-Michel de l'Atalaye. J. S. Brown, collector. March 25, 1921.

9883 (B 331 F). Arrondissement of Marmelade, trail from St.-Michel de l'Atalaye to Dessalines, near Paul. J. S. Brown, collector. March 25, 1921.

9885 (B 332 F). Arrondissement of Dessalines, trail from St.-Michel de l'Atalaye to Dessalines, float at entrance to gap in mountains about 3 kilometers west of Paul. J. S. Brown, collector. March 25, 1921.

9886 (B 333 F). Arrondissement of Dessalines, about halfway down mountain slope between Paul and Dessalines, probably 7 kilometers northeast of Dessalines, altitude 390 meters above sea level. J. S. Brown, collector. March 25, 1921.

9887 (B 334 F.) Arrondissement of Dessalines, float a short distance southwest of 9886, altitude 300 meters above sea level. F. G. Evans, jr., collector. March 25, 1921.

9789 (W 220 F). Arrondissement of Mirebalais, trail from Thomonde to Mirebalais, about 0.5 kilometer southwest of crest of mountains at Bois-Joli, altitude 660 meters above sea level. W. P. Woodring, collector. January 18, 1921.

9919 (W 221 F). Arrondissement of Mirebalais, trail from Thomonde to Mirebalais, float about 3 kilometers southwest of crest of mountains at Bois-Joli, altitude 535 meters above sea level. W. P. Woodring, collector. January 18, 1921.

9456 (W 133 F). Arrondissement of Mirebalais, float on southwest slope of Morne Michel, about 8 kilometers northeast of Mirebalais, altitude 300 meters above sea level. W. P. Woodring, collector. December 6, 1920.

9903 (W 184 F). Arrondissement of Mirebalais, float from gap in mountains along road from Mirebalais to Las Cahobas. W. P. Woodring, collector. January 8, 1921.

9915 (W 202 F). Arrondissement of Mirebalais, trail from Belladère to Savanette, float on south slope of mountains about 4 kilometers northeast of Savanette, altitude 825 meters above sea level. W. P. Woodring, collector. January 13, 1921.

9914 (W 201 F). Arrondissement of Mirebalais, trail from Belladère to Savanette, float on south slope of mountains about 4.5 kilometers northeast of Savanette, altitude 1,100 meters above sea level. W. P. Woodring, collector. January 13, 1921.

9548 (B 119 F). Arrondissement of St.-Marc, railroad cut about 4 kilometers southeast of Mont Rouis. J. S. Brown, collector. December 7, 1920.

9993 (K 56 F). Arrondissement of St.-Marc, trail from l'Arcahaie to Marché Désarmes, 5 kilometers northeast of Couyau halfway down ridge, altitude 1,230 meters above sea level. W. S. Burbank, collector. December 15, 1920.

9502 (K 58 F). Arrondissement of St.-Marc, trail from l'Arcahaie to Marché Désarmes, northeast of Couyau, on crest of ridge overlooking Artibonite Valley. W. S. Burbank, collector. December 15, 1920.

9487 (B 130 F). Arrondissement of St.-Marc, trail from l'Arcahaie to Marché Désarmes, float on slope of Morne Archévêque, about 11 kilometers southwest of Marché Désarmes. J. S. Brown, collector. December 16, 1920.

9486 (B 129 F). Arrondissement of Port-au-Prince, trail from l'Arcahaie to Marché Désarmes, 1 kilometer southwest of habitation Caille-Mare. J. S. Brown, collector. December 14, 1920.

9459 (W 144 F). Arrondissement of Port-au-Prince, trail from Fond-des-Orangers to the Cul-de-Sac Plain, float on north slope of ridge south of Fond-des-Orangers, altitude 610 meters above sea level. W. P. Woodring, collector. December 8, 1920.

9790 (W 313 F). Arrondissement of Port-au-Prince, road from Port-au-Prince to Mirebalais, float on north slope of Morne Terre-Rouge, altitude 590 meters above sea level. W. P. Woodring, collector. February 28, 1921.

9608 (W 79 F). Arrondissement of Port-au-Prince, north slope of ridge between Rivière Froide and Rivière Momance, along trail leading southward from Carrefour, altitude 360 meters above sea level. W. P. Woodring, collector, November 5, 1920.

9553 (W 11 F). Arrondissement of Port-au-Prince, float on crest of Morne Hôpital, east of triangulation station, altitude 950 meters above sea level. W. P. Woodring and J. S. Brown, collectors. October 9, 1920.

9443 (W 9 F). Arrondissement of Port-au-Prince, north slope of Morne Hôpital, altitude 760 meters above sea level. W. P. Woodring and J. S. Brown, collectors. October 9, 1920.

9584 (W 13 F). Arrondissement of Port-au-Prince, trail from Pétionville to Furcy, about 2 kilometers southwest of Pétionville. W. P. Woodring, and F. G. Evans, jr., collectors. October 12, 1920.

9583 (W 14 F). Arrondissement of Port-au-Prince, trail from Pétionville to Furcy, about 3.5 kilometers southwest of Pétionville. W. P. Woodring, collector. October 12, 1920.

9585 (W 15 F). Arrondissement of Port-au-Prince, trail from Pétionville to Furcy, about 2 kilometers south of Rendez-vous. W. P. Woodring and F. G. Evans, jr., collectors. October 12, 1920.

9587 (W 25 F). Arrondissement of Port-au-Prince, trail from Pétionville to Furcy, upper part of village of Kenskoff, altitude 1,515 meters above sea level. W. P. Woodring, and F. G. Evans, jr., collectors. October 14, 1920.

9505 (W 33 F). Arrondissement of Port-au-Prince, trail from Fond-Parisien to Fond-Verrettes, about 3 kilometers south-southeast of Fond-Parisien, altitude 275 meters above sea level. W. P. Woodring, collector. October 21, 1920.

9594 (W 37 F). Arrondissement of Saltrou, trail from Fond-Verrettes to Grand-Gosier, south slope of mountains near crest, altitude 1,570 meters above sea level. W. P. Woodring, collector. October 22, 1920.

9596 (W 39 F). Arrondissement of Saltrou, trail from Fond-Verrettes to Grand-Gosier, south slope of mountains about 13 kilometers northeast of Grand-Gosier, altitude 940 meters above sea level. W. P. Woodring, collector. October 23, 1920.

9510 (W 50 F). Arrondissement of Saltrou, trail from Grand-Gosier to Saltrou, 6 kilometers northwest of Grand-Gosier, altitude 210 meters above sea level. W. P. Woodring, collector. October 28, 1920.

9511 (W 51 F). Arrondissement of Saltrou, trail from Saltrou to Marigot, 4.5 kilometers west of Saltrou, altitude 50 meters above sea level. W. P. Woodring, collector. October 30, 1920.

9444 (W 52 F). Arrondissement of Saltrou, trail from Saltrou to Marigot, about 7.5 kilometers west of Saltrou, altitude 45 meters above sea level. W. P. Woodring, collector. October 30, 1920.

9513 (W 54 F). Arrondissement of Saltrou, trail from Saltrou to Marigot, about 12.5 kilometers west of Saltrou, altitude 350 meters above sea level. W. P. Woodring, collector. October 30, 1920.

9600 (W 59 F). Arrondissement of Jacmel, trail from Marigot to Jacmel, float 6 kilometers west of Marigot. W. P. Woodring, collector. October 31, 1920.

9605 (W 69 F). Arrondissement of Jacmel, right bank of Rivière Gosseline at Passe la Voûte, fourth crossing above Jacmel. W. P. Woodring and F. G. Evans, jr., collectors. November 3, 1920.

9649 (K 28 F). Arrondissement of Jacmel, trail from Bainet to Jacmel, about halfway up south slope of Morne Fontai. W. S. Burbank, collector. November 14, 1920.

9517 (W 81 F). Arrondissement of Nippes, road from Miragoâne to Petit-Goave about 0.5 kilometer east of Miragoâne, altitude 45 meters above sea level. W. P. Woodring, collector. November 14, 1920.

9518 (W 88 F). Arrondissement of Nippes, road from Miragoâne to Aquin, float about a kilometer south of Chapelle de Virgile, altitude 275 meters above sea level. W. P. Woodring, collector. November 15, 1920.

9547 (B 114 F). Arrondissement of Nippes, float on trail from Baradères to Petit-Trou de Nippes, about halfway between the towns. J. S. Brown, collector. November 22, 1920.

9509 (B 56 F). Arrondissement of Cayes, bluff a kilometer west of Camp Perrin. J. S. Brown, collector. November 5, 1920.

9631 (B 82 F). Arrondissement of Tiburon, trail from Anse d'Hainault to Dame-Marie, float on small hill just north of Bariadèle. J. S. Brown, collector. November 15, 1920.

9632 (B 83 F). Arrondissement of Tiburon, float on trail from Anse d' Hainault to Dame-Marie, about 2 kilometers north of 9631. J. S. Brown, collector. November 15, 1920.

9629 (B 84 F). Arrondissement of Tiburon, trail from Dame-Marie to Sources Chaudes, about 6 kilometers east of Dame-Marie. J. S. Brown, collector. November 16, 1920.

9682 (W 177 F). Gonave Island, about 200 meters S. 60° E. of triangulation station at Fond-Plaisir in southeastern part of island. W. P. Woodring, collector. December 26, 1920.

9669 (W 163 F). Gonave Island, trail from Anse-à-Galets to Picmi, about 2 kilometers north of Picmi, altitude 180 meters above sea level. W. P. Woodring, collector. December 19, 1920.

9670 (W 164 F). Gonave Island, trail from Anse-à-Galets to Picmi, float about 1.5 kilometers north of Picmi, altitude 70 meters above sea level. W. P. Woodring, collector. December 19, 1920.

9668 (W 162 F). Gonave Island, trail from Anse-à-Galets to Picmi, bottom of ravine at spring north of Picmi. W. P. Woodring, collector. December 19, 1920.

9665 (W 158 F). Gonave Island, trail leading southwestward from Anse-à-Galets, about 4 kilometers from Anse-à-Galets, altitude 310 meters above sea level. W. P. Woodring, collector. December 18, 1920.

9681 (W 176 F). Gonave Island, trail from Anse-à-Galets to Fond-l'Aurore, about 6 kilometers southeast of Anse-à-Galets. Altitude 380 meters above sea level. W. P. Woodring, collector. December 26, 1920.

9671 (W 165 F). Gonave Island, trail from Anse-à-Galets to Plaine des Mapoux, about 2 kilometers west-northwest of triangulation station on Morne Chien Content. W. P. Woodring, collector. December 20, 1920.

9672 (W 166 F). Gonave Island, trail from Anse-à-Galets to Plaine des Mapoux, about a kilometer east of east end of Plaine des Mapoux, altitude 525 meters above sea level. W. P. Woodring, collector. December 20, 1920.

9673 (W 167 F). Gonave Island, northwest corner of Plaine des Mapoux, altitude 540 meters above sea level. W. P. Woodring, collector. December 21, 1920.

9674 (W 168 F). Gonave Island, north slope of Morne la Pierre, about half a kilometer northeast of triangulation station, altitude 700 meters above sea level. W. P. Woodring, collector. December 21, 1920.

Oligocene Series.

Oligocene deposits in narrow bands usually border upper Eocene limestone along the lower slopes of the mountain ranges. These Oligocene bands consist principally of limestone that can scarcely be distinguished from the upper Eocene limestone except by the fossils it contains.

LOWER OLIGOCENE.

None of the deposits seen during the reconnaissance are considered of undoubted lower Oligocene (Lattorfian) age, as none of them contain Lepidocyclinas of the type of *L. mantelli* (Morton), a species which, in the southeastern United States, is confined to the lower part of the Vicksburg group (Marianna limestone). Some of the limestone in the Chaîne des Mateux, on the north slope of Morne Hôpital (pp. 130-131), east and south of Dondon (pp. 111-112) and elsewhere, described as upper Eocene, may be lower Oligocene. These deposits are unfossiliferous or contain fossils that have no stratigraphic value. Deposits of lower Oligocene age might be expected in such regions as the Chaîne des Mateux, where the series from upper Eocene to Miocene seems to be conformable.

MIDDLE OLIGOCENE.

Middle Oligocene deposits were seen principally in isolated exposures or as float, and at most places their stratigraphic and structural relations are obscure. As their lithology differs at different places no general description of them can be given.

Description by Regions.

Massif du Nord.

A typical middle Oligocene fauna was obtained from a float boulder of yellowish white limestone in a ravine a few hundred meters northwest of the town of Bahon (see list, p. 150, station 9884). The country rock at this place is quartz diorite, and the float in the ravine consists principally of quartz diorite and of slaty argillite of supposed lower or middle Cretaceous age, but limestone boulders, which have probably been transported from an unexplored locality some kilometers to the southwest, are fairly common.

Rocks of known or supposed middle Oligocene age are exposed in a large area along the northern border of the Central Plain near St.-Raphaël. They were examined along the trail from St.-Raphaël to Dondon for a distance of about 3 kilometers, where they overlie limestone of supposed upper Eocene age (see pp. 111-112) and dip southward or southeastward beneath the younger rocks of the plain.

The lowest beds, which are exposed farthest north, consist mainly of brown or gray marl and fine-grained sandstone in very even, rather soft beds, from 2 to 5 centimeters thick, which occupy a small lowland along the narrow valley of Rivière Bouyaha. Lithologically they are similar to some Miocene rocks. A few beds of coarser material containing small pebbles of white limestone, presumably upper Eocene, suggest an erosional unconformity. Interbedded with the sand and marl are thicker beds of brown crystalline limestone containing the Foraminifera listed on page 150, stations 9877 and 9878.

Overlying these clastic beds to the south, at the border of the plain, is pure limestone, white and partly crystalline, thick-bedded or massive, and hard, forming steep walls along the gorge of Rivière Bouyaha. The Foraminifera listed on p. 150, station 9876, were collected from this limestone.

As the dips along the trail appear to be invariably to the south or southeast, and as the width of outcrop is at least 3 kilometers, the total thickness of middle Oligocene at this locality is several hundred meters.

Massive limestone underlies the Pic de Pignon, a conspicuous conical hill north of Pignon. The middle Oligocene Foraminifera listed on page 150, station 9940, were collected from loose pieces of limestone at the foot of the hill. This limestone, which is apparently the same as the massive

limestone along Rivière Bouyaha below St.-Raphaël, forms the ridge extending southeastward from Pignon.[1]

Northwest Peninsula.

Trois Rivières Valley.—Rocks of middle Oligocene age are apparently widely distributed in the Trois Rivières Valley north of Gros-Morne. All the rocks in this trough are folded in narrow anticlines and synclines which are parallel to the length of the trough. The relations of the middle Oligocene to the upper Oligocene south of Gros-Morne and to the Miocene in the lower part of the valley were not determined. The middle Oligocene rocks were seen on the east side of Les Trois Rivières along an unfrequented trail from Gros-Morne to Port-de-Paix. The corals listed on page 150, station 9756, were collected from pieces of hard gray limestone weathered from an outcropping ledge about 9 kilometers north of Gros-Morne. Float containing similar corals was collected a short distance farther north (see list, p. 150, station 9757). Beds of marl, shale, sandstone, and a conglomerate consisting entirely of large cobbles of basaltic rock crop out along the trail north and south of this locality. These beds were seen only in isolated exposures, and as their folding is complex the question whether all the rocks involved are of middle Oligocene age could not be determined.

Montagnes de Jean Rabel.—A series of brown or gray marls containing many thick beds of dense yellowish limestone is exposed along the trail from Jean Rabel to Anse Rouge just south of the crest of the Montagnes de Jean Rabel. These beds overlie upper Eocene limestone and probably overlap it in the area to the north, where they rest on quartz diorite. To the south they dip beneath marly beds of supposed Miocene age underlying the Arbre Plain. An *Operculina,* apparently a common undescribed middle Oligocene species, was collected from one of the beds of limestone. (See list, p. 150, station 9962). The boundary between Oligocene and Miocene in this locality was not determined.

Montagnes de Terre-Neuve.—About 5 kilometers southeast of Terre-Neuve, at a place known as Hilaire, just east of the mineral prospects known as Casseus and Germinie, the mountain side is covered with large float blocks of limestone, gray on weathered surfaces and white in the interior, similar to the prevailing upper Eocene limestone. Some of the boulders contain numerous specimens of *Operculina,* apparently of middle Oligocene age, etched out on weathered surfaces. (See list, p. 150, stations 9810 and 9812.) The collection listed at page 144, station 9813, probably of upper Eocene age, was obtained in the same locality. The middle Oligocene float probably represents rock in place somewhere on the high mountain ridge to the east, at the locality just north of Habitation Dumuraille.

[1] On the map of the Central Plain, Pl. XXXVI, the limestone near Pignon and St.-Raphaël is incorrectly shown as upper Oligocene.

Montagnes Noires.

Thin-bedded chalky limestone crops out on the northeast slope of the Montagnes Noires, in the section called Bois-Joli, along the trail from Mirebalais through Dufailly to Thomonde. The beds strike N. 40° W. and dip 20° NE. Pieces of chert lying on the surface of the limestone contain numerous specimens of the middle Oligocene Foraminifera listed on page 150, station 9918. The chert probably came from bands or nodules in the chalky limestone, although none were seen in the exposure. Lithologically this limestone is indistinguishable from thin-bedded chalky upper Eocene limestone containing bands of chert.

Chaîne des Mateux.

Some of the limestone on the north flank of the Chaîne des Mateux is of middle Oligocene age. Thin-bedded white brittle limestone containing chert nodules crops out at the foot of the mountains south of Savane Madame Michel, on the trail from Saut d'Eau to Fond-des-Orangers. A piece of chert lying loose on the trail contained the middle Oligocene Foraminifera listed on page 150, station 9658. The nephelite basalt described on pages 314-318 overlies this limestone. Farther northwest, on both flanks of the Chaîne des Mateux, limestone of supposed Oligocene age crops out. It is described on page 153.

Montagnes du Trou d'Eau.

Middle Oligocene limestone probably extends eastward from the Chaîne des Mateux, as a *Lepidocyclina* similar to *L. canellei yurnagunensis* Cushman was obtained from float on the south slope of the Montagnes du Trou d'Eau along the road from Port-au-Prince to Mirebalais (see list, p. 150, station 9900).

Near Jacmel.

Granular white limestone containing nodules of chert is exposed in the northernmost sea cliff on the west side of Jacmel Bay, just south of the mouth of a small stream. The bedding in this exposure is not apparent, but the rock is probably crumpled, as pieces from almost any part of the exposure are slickensided. A network of thin seams in the rock contains dark-brown clay. This limestone contains the largest foraminiferal fauna discovered in any of the Tertiary rocks of Haiti. In addition to the species listed on page 150, station 9601, the limestone contains some small undetermined Foraminifera. This is one of the few localities where it is possible to obtain entire tests from the rock. The tests stand out in relief on weathered surfaces and can easily be dug out, as the rock is soft. This is the only locality on the south coast where fossils of middle Oligocene age were collected.

Fossils.

Foraminifera are the most abundant middle Oligocene fossils. They include species of *Lepidocyclina* described by Cushman from Antigua and Cuba and an undescribed species of *Operculina* found in Antigua and other regions. Foraminifera are particularly abundant at station 9601, on the west side of Jacmel Bay, where hand specimens containing hundreds of tests of *Lepidocyclina* can be obtained. The few corals collected are similar to species from Antigua. The same fauna has been found at many localities in the Dominican Republic, in other parts of the West Indies, and in Georgia. The Antigua formation of the island of Antigua, which contains an unusually rich coral fauna, is the type formation of this horizon. On account of its stratigraphic relations in Georgia and of its corals it is correlated with the Rupelian of Italy.[1]

Stations—Middle Oligocene.

9884 (B 298 F). Arrondissement of Grande-Rivière du Nord, float in ravine about a kilometer west of Bahon. J. S. Brown, collector. March 10, 1921.

9876 (B 290 F). Arrondissement of Grande-Rivière du Nord, trail from St.-Raphaël to Dondon, about a kilometer north of St.-Raphaël. J. S. Brown, collector. March 7, 1921.

9877 (B 291 F). Arrondissement of Grande-Rivière du Nord, trail from St.-Raphaël to Dondon, about 3 kilometers north of St.-Raphaël. J. S. Brown, collector. March 7, 1921.

9878 (B 292 F). Arrondissement of Grande-Rivière du Nord, trail from St.-Raphaël to Dondon, about 200 meters north of 9877. J. S. Brown, collector. March 9, 1921.

9940 (W 264 F). Arrondissement of Grande-Rivière du Nord, float at foot of Pic de Pignon, 0.5 kilometer east of Pignon, altitude 365 meters above sea level. W. P. Woodring, collector. February 7, 1921.

9756 (W 291 F). Arrondissement of Port-de-Paix, trail from Gros-Morne to Port-de-Paix on right side of Les Trois Rivières, about 2 kilometers north of crossing of Rivière l'Aqui. W. P. Woodring, collector. February 17, 1921.

9757 (W 292 F). Arrondissement of Port-de-Paix, trail from Gros-Morne to Port-de-Paix on right side of Les Trois Rivières, float about 4 kilometers north of crossing of Rivière l'Aqui. W. P. Woodring, collector. February 17, 1921.

9962 (K 125 F). Arrondissement of Môle St.-Nicolas, trail from Jean Rabel to Anse Rouge, south slope of mountains in valley of Rivière de Port-à-Piment, about 20 kilometers south of Jean Rabel. W. S. Burbank, collector. February 3, 1921.

9810 (B 160 F). Arrondissement of Gonaïves, float at Germinie, in Terre-Neuve region, south of Casseus prospect. J. S. Brown, collector. January 12, 1921.

9812 (B 162 F). Arrondissement of Gonaïves, float south of Germinie in Terre-Neuve region. J. S. Brown, collector. January 12, 1921.

9918 (W 219 F). Arrondissement of Las Cahobas, trail from Thomonde to Mirebalais, float on northeast slope of mountains at Bois-Joli, near crest, altitude 610 meters above sea level. W. P. Woodring, collector. January 17, 1921.

[1] Vaughan, T. W., Fossil corals from Central America, Cuba, and Porto Rico, with an account of the American Tertiary, Pleistocene, and Recent coral reefs: U. S. National Museum Bull. 103, pp. 199 and 202, 1919.

9658 (W 140 F). Arrondissement of Mirebalais, trail from Saut d'Eau (Ville Bonheur) to Fond-des-Orangers, float at foot of mountains about 6 kilometers southwest of Saut d'Eau, altitude 500 meters above sea level. W. P. Woodring and F. G. Evans, jr., collectors. December 8, 1920.

9900 (W 179 F). Arrondissement of Port-au-Prince, road from Port-au-Prince to Mirebalais, float on south slope of mountains, altitude 360 meters above sea level. W. P. Woodring, collector. January 7, 1921.

9601 (W 60 F). Arrondissement of Jacmel, northernmost sea cliff on west side of Jacmel Bay. W. P. Woodring, collector. November 1, 1920.

Middle Oligocene fossils.

Species.	Stations.													
	Massif du Nord.					Northwest Peninsula.					Montagnes Noires.	Chaîne des Mateux.	Montagnes du Trou d'Eau.	Massif de la Hotte.
	Grande-Rivière du Nord.					Port de Paix.	Môle St.-Nicolas.	Gonaïves.			Las Cahobas.	Mirebalais.	Port-au-Prince.	Jacmel.
	9884	9876	9877	9878	9940	9756	9757	9962	9810	9812	9918	9658	9900	9601
Foraminifera:														
Operculina sp. cf. undescribed species from Antigua	..	×	..	..	..	..	..	×	×	×	×	..	..	..
Heterostegina antillea Cushman ?	..	..	..	..	..	..	..	..	..	..	×	..	..	..
Heterostegina sp.	..	..	..	..	..	..	..	..	..	×	..	..	..	..
Lepidocyclina canellei yurnagunensis Cushman	..	..	×	?	?	..	..	..	..	..	..	..	?	..
Lepidocyclina gigas Cushman	..	..	..	..	..	..	..	..	..	..	×	..	..	..
Lepidocyclina undosa Cushman	×	..	..	..	..	..	..	..	..	..	×	?	..	×
Lepidocyclina undulata Cushman	..	..	..	..	..	..	..	..	..	..	×	×	..	×
Lepidocyclina favosa Cushman	..	..	..	..	..	..	..	..	..	..	..	..	..	×
Lepidocyclina sp. cf. L. praemarginata R. Douvillé	..	..	..	..	..	..	..	..	..	..	×	×	..	×
Lepidocyclina sp. cf. L. sumatrensis (Brady)	..	..	..	..	..	..	..	..	..	..	..	..	..	×
Lepidocyclina sp. cf. L. morgani Lemoine and R. Douvillé	..	..	..	..	..	..	..	..	..	..	×	..	..	×
Lepidocyclina sp.	..	?	..	..	..	..	..	..	..	..	..	..	..	×
Corals:														
Orbicella sp.	..	..	..	..	..	×	..	..	..	..	..	..	..	..
Antiguastrea cellulosa (Duncan) ?	×	..	..	..	..	..	..	..	..	..	..	..	..	..
Favites polygonalis (Duncan) ?	..	..	..	..	..	×	..	..	..	..	..	..	..	..
Cyathomorpha sp. cf. C. belli Vaughan	..	..	..	..	..	..	×	..	..	..	..	..	..	..
Cyathomorpha n. sp.	..	..	..	..	..	×	..	..	..	..	..	..	..	..
Mollusca:														
Pelecypoda:														
Phacoides (Parvilucina) sp.	..	..	..	..	.	..	..	..	..	..	.	..	..	×

UPPER OLIGOCENE.

Rocks of upper Oligocene age seem to be confined to the northern and central parts of the Republic. They consist principally of limestone, generally massive, resembling the massive limestone of Eocene and middle Oligocene age. The upper Oligocene deposits probably are conformable to the middle Oligocene, although the actual contact was not seen. The lithology and thickness differ in the regions where rocks of this age were examined, as is shown below.

Description by Regions.

Tortue Island.

The limestone that covers the interior of Tortue Island is at least 100 meters thick. It is massive, and most of the weathered outcrops on the surface of the plateau are stained red by recemented residual clay. It rests unconformably on a basement of schistose limestone. The structure of the limestone was not determined, but the surface features indicate that it is arched in a broad anticline. The only fossils obtained are the Foraminifera and mollusks listed on page 156 (stations 9761 and 9762). The evidence with regard to age furnished by these fossils is not conclusive, and the limestone may be of Miocene age.

The relation of this limestone to the water supply of the island is discussed on page 541.

Arrondissement of Borgne.

Massive white or grayish limestone crops out in the coastal ridge east of Anse-à-Foleur, in the western part of the Arrondissement of Borgne. The Foraminifera and corals listed on page 156 (stations 9766, 9767, and 9768) were obtained from this limestone. Its stratigraphic and structural relations to the upper Eocene limestone in the same ridge farther east are not known.

Trois Rivières Valley.

The surface rocks in virtually all the southern part of the trough known as the Trois Rivières Valley, which extends northward from Gonaïves to Port-de-Paix, are of upper Oligocene age. These deposits consist of limestone, gray or brown marl, fine-grained sandstone, and shale. Brownish-yellow limestone is interbedded with the marl. The limestone, which is in thick or thin beds, is harder than the marl and crops out in conspicuous ledges. Partly crystalline massive limestone and sandy limestone in thinner beds are exposed in low, bare hills along the west side of the road from Gonaïves to Gros-Morne south of the divide. The Foraminifera listed on page 156 (station 9751) were collected from the massive limestone. The marl is well exposed in cuts along the same road just south of the divide. It has a conchoidal fracture and closely resembles Miocene marl. A bed of limestone interbedded with the marl at a locality about a

kilometer north of the divide contained the Foraminifera listed on page 156 (station 9943).

Along the east and west borders of the trough there are a number of exposures of a white thin-bedded unfossiliferous limestone that commonly is sheeted transverse to the bedding. It seems to be in fault contact with upper Eocene limestone or older volcanic rocks. As the trough has probably been formed by normal faulting (see p. 121), this limestone appears to be younger than Eocene. It is tentatively referred to the upper Oligocene.

The upper Oligocene rocks, like other rocks in the trough, are folded in narrow anticlines and synclines, and the dip and strike change within short distances.

Borders of the Central Plain.

Limestone of upper Oligocene age crops out in the lower slopes of the mountains bordering the southeastern half of the Central Plain. At the northwestern extremity of the plain this limestone seems to be concealed by flood-plain deposits, which are not shown on the map (Pl. I).

The limestone in the mountains bordering the plain from St.-Raphaël southeastward an unknown distance beyond Pignon is middle Oligocene. At Bassin Zinn, northeast of Hinche, where Rivière Samaná cascades down the dip slope of the limestone into the plain, the limestone is of upper Oligocene age. The surface of the limestone along the stream is covered with travertine. A piece of limestone at the foot of the cascade contained the Foraminifera listed on page 156 (station 9936). At this locality the limestone has the same strike and dip as the overlying Miocene conglomerate.

The same limestone was examined along the trail from Thomassique to Cerca-la-Source, where it crops out in the ridge bordering the plain. The Miocene beds in the plain and the upper Oligocene limestone in the ridge dip about 20° SW. The southwest slope of the ridge, which faces the plain, is a dip slope. The northeast slope, which overlooks the valley of Rivière l'Océan, is a steep scarp, apparently a fault scarp. The limestone appears massive in outcropping ledges. The coral listed on page 156 (station 9949) was collected from a loose piece of limestone on the northeast slope.

Massive limestone of supposed upper Oligocene age flanks upper Eocene limestone on the north slope of the Montagnes Noires, along the south side of the plain. It also crops out on the south side of the mountains facing the valley of Rivière Fer-à-Cheval.

On the southwest side of the plain the upper Oligocene limestone crops out in the lower slopes of the Montagnes Noires. It forms the conspicuous hill northwest of Thomonde, on the crest of the Thomonde anticline. The corals listed on page 156 (stations 9934 and 9741) were collected at the foot of this hill. Massive gray limestone of upper Oligocene age was seen on the northeast slope of the mountains on the trail from Thomonde to

Mirebalais through Bois-Joli. The fossils listed on page 156 (stations 9786, 9787, 9917, and 9788) were collected from float derived from this limestone.

Low, isolated hills, which rise above the cover of flood-plain deposits in the northwestern extremity of the plain, between St.-Michel de l'Atalaye and Pignon, are composed of limestone, probably of upper Oligocene age, although it may be middle Oligocene. An indeterminate species of *Goniopora* was collected from this limestone (station 9875).

Chaîne des Mateux.

Along the trail from l'Arcahaie through Couyau to Marché Désarmes a band of limestone of supposed Oligocene age, from 2 to 4 kilometers in width, flanks upper Eocene limestone on the limbs of the anticlinal arch of the Chaîne des Mateux. The band of Oligocene rocks is narrower on the northeast side than on the southwest side because of the steeper dips. The structural relations are shown in Figure 5 (p. 128). On the southwest slope of the mountains the Oligocene rocks are thrust southwestward over Miocene rocks. No fossils were found in the beds of supposed Oligocene age and their age is not definitely known.

The supposed Oligocene limestone rests without apparent discordance on upper Eocene limestone. It is white and partly chalky and contains no chert. In many exposures it is sheeted transverse to the beddings, apparently as a result of fractures produced in folding. The sheeting may obscure the bedding and at places resembles bedding. Most of the sheeting planes are only 2 to 5 centimeters apart and the bedding planes are farther apart. The thickness of this limestone, as can be seen from Figure 5, is at least several hundred meters if not more than 1,000 meters.

Montagnes du Trou d'Eau.

The surface rock in virtually the entire eastern part of the Montagnes du Trou d'Eau east of Morne Trou d'Eau, is limestone of upper Oligocene age. The thickness of this limestone is probably several hundred meters. Its structural relations are obscure because at almost all the localities examined it appears massive.

The limestone is gray or yellowish on weathered surfaces and white on unweathered surfaces. Weathered surfaces in most places are deeply pitted, and at some places the rock forms a solution breccia. The limestone rests on the nephelite basalt described on page 315. A conglomerate at the base of the limestone contains large cobbles of basalt and smaller pebbles of limestone, presumably of upper Eocene age. This conglomerate is well exposed on the trail from Thomazeau to Cornillon, about 1.5 kilometers from Thomazeau.

Numerous collections of fossils were obtained from this limestone along the north shore of Étang Saumâtre and along the trails from Thomazeau

to Cornillon, from Cornillon to St.-Pierre, and from Cornillon to Marché Canard. (See list, p. 156, stations 9898, 9521, 9657, 9556, 9557, 9558, 9451, 9449, 9450, 9559, 9452, 9453, 9560, 9454, and 9561.) Corals are particularly abundant, and at some places—for example, on the crest of the first ridge northwest of Cornillon on the trail to Marché Canard, where large heads of *Orbicella* and branches of *Stylophora* and *Porites* are strewn along the trail—the limestone is a reef rock.

Fossils.

Foraminifera are less abundant in the upper Oligocene limestones than in the older Tertiary rocks. *Sorites americana* (Cushman), described from the Emperador limestone of Panama, and *Miogypsina antillea* (Cushman), described from the Anguilla formation of the island of Anguilla, are the most common species. The deposits south of Gros-Morne contain *Lepidocyclina giraudi,* described by R. Douvillé from beds on the island of Martinique that are considered to be of Aquitanian age by Giraud and of Burdigalian age by Douvillé.[1] This species duplicates in a remarkable fashion the surface sculpture of the Cretaceous species *Orbitoides media* (d'Archiac).

At some localities, particularly in the Montagnes du Trou d'Eau, corals are abundant in the upper Oligocene deposits. Some of the species, such as *Orbicella imperatoris* Vaughan, *Orbicella canalis* Vaughan, and *Siderastrea silecensis* Vaughan, have been described from upper Oligocene rocks in adjacent regions. At least two species, *Stephanocoenia* sp. cf. *S. intersepta* (Esper) and *Goniopora jacobiana* Vaughan, are of Miocene aspect.

The upper Oligocene deposits of the Haitian Republic seem to be of the same age as the upper part of the Culebra formation and the Emperador limestone of Panama and the Anguilla formation of Anguilla. This horizon probably is the equivalent of the Aquitanian, which is called Miocene by most European geologists.

Stations—Upper Oligocene.

9761 (W 298 F). Tortue Island, trail from La Vallée to Pointe des Oiseaux, about 8 kilometers east of La Vallée, altitude 265 meters above sea level. W. P. Woodring, collector. February 20, 1921.

9762 (W 299 F). Tortue Island, trail from La Vallée to Pointe des Oiseaux, steep slope leading down to coast about 3 kilometers northwest of Pointe des Oiseaux, altitude 235 meters above sea level. W. P. Woodring, collector. February 20, 1921.

9766 (W 302 F). Arrondissement of Borgne, trail from Anse-à-Foleur to Le Borgne, float in small stream about 2 kilometers east of Anse-à-Foleur. W. P. Woodring, collector. February 22, 1921.

[1] Douvillé, R., Sur des Lépidocyclines nouvelles: Soc. géol. France Bull., 4th ser., vol. 7, pp. 307-311, pl. 10, figs. 9, 10, 15, 16, text figs. 1, 2, 1907.

9767 (W 303 F). Arrondissement of Borgne, trail from Anse-à-Foleur to Le Borgne, first ridge along coast on east side of Anse-à-Foleur. W. P. Woodring, collector. February 22, 1921.

9768 (W 304 F). Arrondissement of Borgne, float in mountains about 7 kilometers west-northwest of Le Borgne, altitude 195 meters above sea level. W. P. Woodring, collector. February 22, 1921.

9751 (W 276 F). Arrondissement of Gonaïves, road from Gonaïves to Gros-Morne, low hill on northwest side of road about 4 kilometers from Gonaïves. W. P. Woodring and J. S. Brown, collectors. February 15, 1921.

9943 (W 280 F). Arrondissement of Gonaïves, road from Gonaïves to Gros-Morne, about 7 kilometers south of Gros-Morne. W. P. Woodring and J. S. Brown, collectors. February 15, 1921.

9936 (W 244 F). Arrondissement of Hinche, float at foot of cascade on Rivière Samaná at Bassin Zinn. W. P. Woodring, collector. January 31, 1921.

9949 (W 324 F). Arrondissement of Vallière, trail from Thomassique to Cercala-Source, float on north slope of ridge overlooking valley of Rivière l'Océan, altitude 435 meters above sea level. W. P. Woodring, collector. March 13, 1921.

9741 (W 240 F). Arrondissement of Las Cahobas, crest of Thomonde anticline, foot of Morne Mamont, about 4 kilometers west-northwest of Thomonde, altitude 360 meters above sea level. W. P. Woodring, collector. January 29, 1921.

9934 (W 241 F). Arrondissement of Las Cahobas, float at same locality as 9741. W. P. Woodring, collector. January 29, 1921.

9786 (W 215 F). Arrondissement of Las Cahobas, trail from Thomonde to Mirebalais, float about a kilometer southwest of cemetery at Caille-Pain, altitude 480 meters above sea level. W. P. Woodring, collector. January 17, 1921.

9787 (W 216 F). Arrondissement of Las Cahobas, trail from Thomonde to Mirebalais, about 1.5 kilometers southwest of cemetery at Caille-Pain, altitude 485 meters above sea level. W. P. Woodring, collector. January 17, 1921.

9917 (W 217 F). Arrondissement of Las Cahobas, trail from Thomonde to Mirebalais, float about 3.5 kilometers southwest of cemetery at Caille-Pain, altitude 570 meters above sea level. W. P. Woodring, collector. January 17, 1921.

9788 (W 218 F). Arrondissement of Las Cahobas, trail from Thomonde to Mirebalais, float on northeast slope of mountains at Bois-Joli, near crest, altitude 610 meters above sea level; same locality as 9918. W. P. Woodring, collector. January 17, 1921.

9875 (B 289 F). Arrondissement of Grande-Rivière du Nord, float on road from St.-Michel de l'Atalaye to St.-Raphaël, about 8 kilometers southwest of St.-Raphaël. J. S. Brown, collector. March 6, 1921.

9898 (B 350 F). Arrondissement of Port-au-Prince, float 50 meters west of Source Maneville. J. S. Brown, collector. March 30, 1921.

9657 (W 105 F). Arrondissement of Port-au-Prince, float on small island along north shore of Étang Saumâtre, about 6 kilometers southeast of Maneville. W. P. Woodring, collector. November 23, 1920.

9521 (W 104 F). Arrondissement of Port-au-Prince, float short distance east of 9657. W. P. Woodring, collector. November 23, 1921.

9556 (W 114 F). Arrondissement of Port-au-Prince, trail from Thomazeau to Cornillon, south slope of mountains about 10 kilometers northeast of Thomazeau, altitude 640 meters above sea level. W. P. Woodring, collector. December 3, 1920.

9557 (W 116 F). Arrondissement of Mirebalais, trail from Thomazeau to Cornillon, about 2 kilometers northwest of Cornillon, altitude 905 meters above sea level. W. P. Woodring, collector. December 3, 1920.

9558 (W 118 F). Arrondissement of Mirebalais, entrance to cave on north side of trail from Thomazeau to Cornillon, about 3 kilometers northwest of Cornillon, altitude 915 meters above sea level. W. P. Woodring, collector. December 3, 1920.

Species.	Tortue Island.		Massif du Nord.			Northwest Peninsula.	Borders of Central Plain.									Montagnes du Trou d'Eau.														
	Port-de-Paix.		Borgne.			Gonaïves.	Hinche.	Vallière.	Las Cahobas.						Gr. Rivière du Nord.	Port-au-Prince.	Mirebalais.													
	9761	9762	9766	9767	9768	9751	9943	9936	9949	9741	9934	9786	9787	9917	9788	9875	9898	9657	9521	9556	9557	9558	9449	9450	9559	9451	9452	9453	9560	9454	9561
Foraminifera:																															
Sorites americana (Cushman)	..	..	?	..	..	..	..	×	..	..	..	..	?	..	×	..	×	×	×	×	×	×	..	..	..	..	..	..	..	..	..
Orbiculina sp.	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Operculina sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..
Operculina ? sp	×	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Miogypsina antillea (Cushman)	..	..	?	..	..	×	×	..	..	..	..	..	..	..	..	..	..	..	..	..	?	..	..	..	..	..	..	..	..	..	..	..
Lepidocyclina giraudi R. Douvillé	..	..	..	..	..	×	×	..	..	..	..	..	..	..	.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Corals:																															
Stylophora sp. a	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..
Stylophora sp. b	..	..	..	..	..	.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..
Stephanocoenia sp. cf. S. intersepta (Esper)	..	..	..	..	..	.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..
Orbicella imperatoris Vaughan	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	×	..	..	..	..
Orbicella canalis Vaughan	..	..	..	×	×	..	..	..	..	..	×	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Solenastrea sp.[a]	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..
Lamellastrea n. sp	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Siderastrea silecensis Vaughan	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	×
Psammocora n. sp. a	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Psammocora sp.	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Porites sp. aff. P. furcata Lamarck	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..
Goniopora jacobiana Vaughan	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..
Goniopora sp. indet	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..
Mollusca:																															
Gastropoda:																															
Cerithium sp.	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Pelecypoda:																															
Arca sp. cf. A. umbonata Lamarck	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..
Chlamys (Aequipecten) sp. cf. C. (A.) flabellum (Cooke)	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Chlamys (Aequipecten) sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..

[a] Found also in middle and upper Oligocene of Florida and Georgia.

9449 (W 119 F). Arrondissement of Mirebalais, trail from Cornillon to St.-Pierre, cliff along east side of trail about 1 kilometer east of Cornillon. W. P. Woodring, collector. December 3, 1920.

9450 (W 120 F). Arrondissement of Mirebalais, float at same locality as 9449. W. P. Woodring, collector. December 3, 1920.

9559 (W 121 F). Arrondissement of Mirebalais, trail from Cornillon to St.-Pierre, float about 2.5 kilometers east of Cornillon, altitude 1,035 meters above sea level. W. P. Woodring, collector. December 3, 1920.

9451 (W 122 F). Arrondissement of Mirebalais, trail from Cornillon to St.-Pierre, about 5 kilometers southeast of Cornillon, altitude 1,055 meters above sea level. W. P. Woodring, collector. December 3, 1920.

9452 (W 123 F). Arrondissement of Mirebalais, trail from Cornillon to Thomazeau and Mirebalais, float about 2.5 kilometers northwest of Cornillon, altitude 900 meters above sea level. W. P. Woodring, collector. December 4, 1920.

9453 (W 124 F). Arrondissement of Mirebalais, trail from Cornillon to Mirebalais, about 3.5 kilometers northwest of Cornillon, altitude 980 meters above sea level. W. P. Woodring, collector. December 4, 1921.

9560 (W 125 F). Arrondissement of Mirebalais, trail from Cornillon to Mirebalais, float about 3.6 kilometers northwest of Cornillon, altitude 980 meters above sea level. W. P. Woodring, collector. December 4, 1920.

9454 (W 126 F) Arrondissement of Mirebalais, trail from Cornillon to Mirebalais, crest of ridge about 5 kilometers northwest of Cornillon, altitude 1,115 meters above sea level. W. P. Woodring, collector. December 4, 1920.

9561 (W 128 F). Arrondissement of Mirebalais, trail from Cornillon to Mirebalais, float on north slope of mountains about 10 kilometers northwest of Cornillon, altitude 870 meters above sea level. W. P. Woodring, collector. December 4, 1920.

Miocene Series.

Rocks of Miocene age are widely distributed in the plains and lowlands of the Republic and have a maximum thickness of more than a thousand meters. Probably all of them are lower and middle Miocene. The Miocene fossils in the different regions are so diverse that a short account of them is given for each region.

GENERAL FEATURES.

Areal distribution.—The largest areas of Miocene deposits are in the Central Plain and the Artibonite Valley. Other areas are shown on Plate I. The larger areas shown are in plains or lowlands, and in other regions the Miocene rocks are restricted to lowlands; at few places are they found at altitudes of more than 400 meters above sea level. They were not seen on the crests of any of the mountain ranges, although they formerly extended over some ranges. Some lowlands, such as the Cul-de-Sac Plain, the lower part of the Artibonite Plain, and most of the Arbre Plain, contain Miocene rocks, but they are almost wholly concealed by Quaternary alluvium.

Stratigraphic relations.—The transgression of the Miocene sea was extensive, and at places the Miocene overlaps the Eocene or even older rocks. Around the borders of the Central Plain and at other places where

the Miocene rests on upper Oligocene there is no unconformity between them and the change in lithology is gradual. In the northwest Peninsula, where Miocene rocks rest on Eocene rocks, there is little or no evidence of unconformity, the strike and dip of the two series being nearly the same; neither is there any conglomerate at the base of the Miocene, although the change in lithology is abrupt. At a few places the Miocene appears to rest in marked unconformity on rocks older than Eocene.

Lithology.—The Miocene rocks consist principally of detrital deposits. Most of them are fine grained, consisting of clay, siltstone, sandstone, and marl. Unweathered surfaces of these rocks at most places are bluish or greenish, but on weathered outcrops they are yellowish brown or gray. The marl is highly calcareous, as is shown by the analysis on page 502 of a sample from a locality north of St.-Marc. On a moisture-free basis the sample contained more than 57 per cent of calcium carbonate. Beds of impure yellowish limestone from a few centimeters up to a meter in thickness are interbedded with the marl at some localities. At other places there are thicker beds of coralliferous limestone. Close to old land masses the rocks are coarser, consisting of conglomerate and coarse sandstone. In the Central Plain, the Asile Valley, and the lowland at Camp Perrin the Miocene deposits contain beds of lignite. Although the unweathered Miocene rocks are firmly consolidated most of them are soft and crumble readily in the hand when weathered.

Most of the Miocene deposits are of shallow-water marine origin, but some of the deposits in the Central Plain were laid down in coastal-plain swamps and on flood plains. The Miocene rocks of the Asile Valley and the lowland at Camp Perrin are entirely nonmarine, consisting of lake, swamp, delta, and flood-plain deposits.

Thickness.—The thickness of the Miocene rocks differs greatly in different localities. In all the large areas it reaches at least several hundred meters. The estimated thickness in the Central Plain is 1,400 meters. Near La Chapelle in the Artibonite Valley a thickness of about 700 meters is exposed. In the area northeast of St.-Marc 300 meters of Miocene rocks are exposed, but the base of the series was not seen. Near Camp Perrin the thickness is at least 500 meters.

Structure.—The Miocene rocks are folded and in many localities crumpled. Structurally the two largest areas of Miocene rocks, the Central Plain and the Artibonite Valley, are synclines. Some of the details of the structure are given in the following pages. The structural features of the Central Plain are described on pages 488-492.

DESCRIPTION BY REGIONS.

Jean Rabel Valley.

Much if not all of the lowland called the Jean Rabel Valley is underlain by soft Miocene rocks, which are easily eroded. In the northern part of the lowland, however, at least near Jean Rabel, the Miocene rocks are covered

by Quaternary alluvium. Good exposures are found in the plateau region to the south.

The Miocene rocks of the area were examined hurriedly near Jean Rabel and in the vicinity of Rivière Cadet and of Rivière de Jean Rabel, to the southwest and southeast, respectively, of the town. They consist principally of thin-bedded marl or sandy marl, generally bluish, but at a few places of a gray or yellow tint. The marl commonly has the typical conchoidal fracture shown in Plate XIV, *C*, page 168. Most of the sandy beds are fine grained, but beds of coarse sandstone were seen on Rivière de Jean Rabel about a kilometer southeast of Jean Rabel. Beds of coarse sandstone and conglomerate are conspicuous near the southern border of the lowland. They are yellowish and rather firmly consolidated.

Just west of Jean Rabel the Miocene beds are sharply tilted and generally dip 30°–40° N. Farther south, however, the dips flatten and become variable. The general inclination along Rivière Cadet seems to be slightly to the north, but along the ridge to the east the beds of conglomerate for a considerable distance dip a few degrees to the south. Along Rivière de Jean Rabel the general strike is northeastward, varying, however, within the limits of north and east. The dips are 15° to 30°, generally northwestward so far as observed. The southward extension of the areas of Miocene beds along these two river valleys as reentrants into regions flanked by upper Eocene limestone and the divergence of the strikes at numerous places from the general east and west elongation of the lowland suggest that the valleys may be the troughs of minor synclines whose axes trend approximately northward.

At a large spring about 5 kilometers south by east from Jean Rabel along the trail to Anse Rouge, near Rivière de Jean Rabel, the contact of Miocene with upper Eocene limestone is unusually well exposed. Both series of rocks dip northward at about the same angle, 15° or 20°, but the change in lithology is abrupt and complete. The upper Eocene consists of hard white limestone containing numerous Foraminifera. The Miocene is a bluish sandy marl, but there is no trace of a basal conglomerate.

The relations appear to be similar on Rivière Cadet about 4 or 5 kilometers southwest of Jean Rabel, but the actual contact could not be found. The upper Eocene limestone, which contains many Foraminifera, dips northeastward at an angle of about 15° beneath fine-grained sandy and marly Miocene beds that dip gently northward.

No estimate was obtained of the thickness of the Miocene beds exposed in this area, but it probably reaches some hundreds of meters.

So far as observed the Miocene beds of the Jean Rabel Valley are unfossiliferous. They are considered of Miocene age on stratigraphic and lithologic grounds.

Trois Rivières Valley.

Rocks similar to the Miocene rocks of the Jean Rabel Valley extend up the Trois Rivières Valley for an undetermined distance. Their relations

to the Oligocene deposits of this valley are not known. Exposures in high bluffs along the lower part of the river show that they are made up of marl, sandstone, and siltstone. The beds generally strike parallel to the valley and dip to the east or west.

Sandstone and shale, probably of Miocene age, crop out along the road leading westward from Port-de-Paix to the crossing of Les Trois Rivières. Similar detrital rocks extend along the north coast from Port-de-Paix southeastward to Cap Rouge at the eastern boundary of the arrondissement of Port-de-Paix. They dip to the northeast toward the sea and overlie limestone of upper Oligocene age.

Near Môle St.-Nicolas.

The Rivière du Môle south of Môle St.-Nicolas occupies a deep, canyon-like valley cut mainly in Quaternary coralliferous limestone. At La Gorge, about 3 kilometers south of Môle St.-Nicolas, the valley widens and is floored with Miocene marl. The average width of the area underlain by the Miocene beds probably is about half a kilometer. The area is at least 2 kilometers and very likely 3 or 4 kilometers in length.

The soft marl disintegrates readily into greenish clayey soil. The best exposure was found in an excavation along the trail leading to Bombardopolis, about 2 kilometers south of La Gorge, at an altitude of about 95 meters above sea level and 25 meters above the river bed. The marl is greenish in color and contains a few fragments of mollusks. The bedding was not visible, as the rocks in the exposure had slumped. Marl from this excavation was being tried in making bricks at La Gorge. (See p. 506.)

The contact of the Miocene with the overlying coralliferous limestone is about 100 meters above sea level along the trail just above the excavation but is not well exposed. The Miocene beds generally seem to extend to elevations from 15 to 30 meters above the river bed. The coralliferous limestone generally forms steep bluffy slopes above the contact.

The Miocene rocks exposed on this stream are probably continuous under the cover of Quaternary limestone with the extensive area of similar rocks in the Jean Rabel Valley.

Arbre Plain.

The Arbre Plain, a lowland on the south side of the northwest Peninsula, resembles in many features the Jean Rabel Valley. Rocks of Miocene age underlie probably the entire plain but are concealed by alluvium in its lower part. They consist of marl, conglomerate, and limestone. A Miocene coral was collected from a conglomerate containing poorly preserved corals and mollusks (station 9846). The conglomerate is about 2 meters thick and is overlain and underlain by bluish marl. At this locality the beds are approximately horizontal. Just north of this exposure there is a low hill of weathered, pitted limestone, probably massive Eocene limestone, which crops out from beneath the Miocene rocks.

Miocene marl was found in a low bluff along a dry stream channel on the trail from the Sources Chaudes to Anse Rouge, a little more than a kilometer southwest of the Sources Chaudes and just north of a prominent low hill called Morne Meron. The marl is bluish and clayey and showed no bedding planes.

The contact between Miocene marl and thin-bedded limestone and similar rocks of middle Oligocene age is exposed at the northern edge of the plain on the trail from Anse Rouge to Jean Rabel. The two series of rocks seem to be conformable. At the Sources Chaudes there is evidence that the contact between Miocene and older limestone, of supposed Eocene age, is a fault. (See p. 561.)

Fossils.—The single collection of fossils from the Miocene rocks of the Arbre Plain is given in the following table. The coral *Psammocora* n. sp. was obtained also from the upper part of the Thomonde formation in the Central Plain.

Station in Arbre Plain (Miocene).

9846 (B 213 F). Arrondissement of Gonaïves, trail from Sources Chaudes to l'Arbre, about 3 kilometers west-northwest from Sources Chaudes. J. S. Brown, collector. February 4, 1921.

Fossil (coral) from station 9846.

Psammocora n. sp. b, also from Miocene of Trinidad.

Central Plain.

Artibonite group.

The Miocene rocks of the Central Plain are better known than those of any other region in the Republic. Tippenhauer[1] and Jones[2] have described some of the Miocene deposits of the plain, and a preliminary report setting forth the results of the reconnaissance has been published.[3] Structurally the plain is a deep southeastward-plunging syncline modified by secondary synclinal and anticlinal folds. It contains an estimated thickness of 1,400 meters of Miocene rocks, for which Woodring[4] has recently proposed the name Artibonite group, derived from Rivière Artibonite. The Artibonite group is the equivalent of the lower part of the Yaque group of the Dominican Republic. It consists of the following formations:

[1] Tippenhauer, L. G., Beiträge zur Geologie Haïti, VI, Das Lignitlager von Maïssade und der Aufstieg zum Zentralplateau von Gonaïves und von Norden aus: Petermanns Mitt., Band 47, pp. 193-199, pls. 15, 16 (map and sections), 1901; Neuer Beitrag zur Topographie, Bevölkerungskunde und Geologie Haitis: Petermanns Mitt., Band 55, pp. 49-57, pl. 5 (map), 1909.

[2] Jones, W. F., A geological reconnaissance in Haiti; a contribution to Antillean geology: Jour. Geology, vol. 26, pp. 728-752, pl. 5 (map and sections), 10 text figs., 1918.

[3] Woodring, W. P., Stratigraphy, structure, and possible oil resources of the Miocene rocks of the Central Plain, 19 pp., map, Rep. Haiti Geol. Survey, 1922.

[4] Woodring, W. P., op. cit., p. 6.

Formations comprised in the Artibonite group.

	Approximate thickness in meters.
Las Cahobas formation	600-700
Thomonde formation (including Maïssade tongue in northwestern part)	300-600
Madame Joie formation	100

The distribution of these formations is shown on Plate XXXVI (p. 488).

MADAME JOIE FORMATION.

The name Madame Joie formation has been proposed for the lowest group of Miocene rocks in the plain.[1] The name is derived from Madame Joie, a village about 10 kilometers west of Maïssade, and the type locality is at the foot of Morne Madame Joie, about 1 kilometer southwest of the

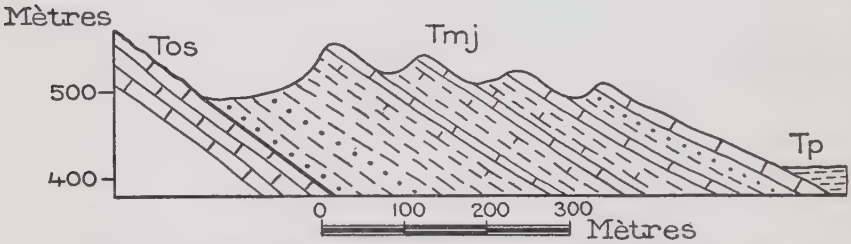


FIGURE 9.—Diagrammatic section of foothills at Morne Madame Joie.

Tp, Pliocene (?) clay; Tmj, Madame Joie formation, lower Miocene; Tos, upper Oligocene limestone.

village. It crops out at the base of the mountains along the western and southern margins of the plain.

The Madame Joie formation overlies the upper Oligocene limestone, but the actual contact was not seen. Apparently there is no unconformity between them, but rocks that probably are the equivalent of the Madame Joie formation elsewhere directly overlie Eocene deposits.

At the type locality the formation is made up of a lower part consisting of bluish-gray siltstone and an upper part consisting of coralliferous limestone, sandstone, and marl. The following section was measured at the type locality. Each of the coralliferous limestones in the upper part of the formation crops out in a prominent ledge that has a long dip slope facing toward the plain, as shown in Figure 9. The soft lower part of the formation underlies the gap between the ridge formed by the coralliferous limestones and the main part of Morne Madame Joie.

[1] Woodring, W. P., op. cit., p. 6, 1922.

Section of Madame Joie formation at foot of Morne Madame Joie.

	Est. thickness in meters.
12. Limestone, coralliferous, cream-colored; station 9720	5
11. Sandstone, calcareous, yellow	2
10. Siltstone, sandy, yellowish brown	1
9. Marl, light yellow	1
8. Limestone, coralliferous, dirty white; station 9937	5
7. Siltstone, marly, light brown	2
6. Marl, yellowish brown	1
5. Limestone, coralliferous, dirty white; station 9938	5
4. Marl, light yellow	1
3. Siltstone, marly, yellowish brown	2
2. Limestone, coralliferous, light yellow	5
1. Siltstone, bluish gray, not well exposed	30
	60

The beds strike N. 50° W. and dip 25°–33° NE. At the foot of the ridge lie clays of Pliocene or Quaternary age that probably conceal higher beds in the formation.

On the Thomonde anticline[1] the Madame Joie formation consists of the same kinds of rocks. Limestone and yellowish-white marl in the upper part of the formation form a low ridge that arches over the plunging crest of the anticline about 2 kilometers northwest of Thomonde. Bluish-gray siltstone in the lower part of the formation crops out along a small stream that flows nearly on the crest of the anticline inside the ridge. The mollusks listed on page 164, station 9933, were collected from the siltstone along this stream. Similar mollusks (see list, p. 164, station 9784) were collected from yellowish-gray marl, probably in the upper part of the formation, on the south limb of the Thomonde anticline.

At the south edge of the plain the Madame Joie formation was examined only along the trail from Belladère to Savanette. Here the formation seems to consist entirely of marl, from which the pteropods listed on page 164, station 9912, were obtained. The marl crops out in the mountain slope facing the plain at an altitude of 460 meters above sea level.

Fossils.—The coralliferous limestones in the upper part of the formation at the type locality contain huge heads of *Orbicella canalis* Vaughan and *Orbicella altissima* Duncan (?). *O. canalis* has not heretofore been recorded from rocks younger than upper Oligocene, but it was found in Miocene deposits at a number of localities in the Republic of Haiti.

The molluscan fauna of the Madame Joie formation is meager, consisting principally of pteropods of the genera *Cavolina* and *Styliola.* At some localities, particularly station 9912, the pteropods are very abundant but poorly preserved. The presence of these pteropods and of the bivalve mollusks *Bathyarca* and *Limopsis* and the absence of common shoal-water

[1] See pp. 488-492 and Pl. XXXVI for description and location of anticlines in the Central Plain.

mollusks indicate that these sediments were deposited in clear water at some distance from land. The depth of the water may have been greater when the lower part of the formation was being laid down than when the upper part and the later formations were being deposited.

The Madame Joie formation is either Aquitanian or Burdigalian. Although the evidence is not very conclusive it seems to be lower Burdigalian. It marks the beginning of the change from the limestones of the Eocene and Oligocene to the detrital deposits of the Miocene.

The Madame Joie fossils and the localities at which they were collected are given in the following table.

Stations in Central Plain—Madame Joie formation (Miocene).

9720 (W 257 F). Arrondissement of Hinche, lower slopes of Morne Madame Joie, about 1 kilometer southwest of Madame Joie, from uppermost coralliferous limestone, altitude 400 meters above sea level. W. P. Woodring, collector. February 3, 1921.

9937 (W 258 F). Arrondissement of Hinche, lower slopes of Morne Madame Joie, from middle coralliferous limestone, altitude 430 meters above sea level. W. P. Woodring, collector. February 3, 1921.

9938 (W 259 F). Arrondissement of Hinche, lower slopes of Morne Madame Joie, from lower coralliferous limestone, altitude 465 meters above sea level. W. P. Woodring, collector. February 3, 1921.

9933 (W 239 F). Arrondissement of Las Cahobas, crest of Thomonde anticline, about 3 kilometers west-northwest of Thomonde, altitude 315 meters above sea level. W. P. Woodring, collector. January 29, 1921.

9784 (W 213 F). Arrondissement of Las Cahobas, south limb of Thomonde anticline, trail from Thomonde to Mirebalais, crossing of ravine about 4 kilometers southwest of Thomonde, altitude 305 meters above sea level. W. P. Woodring, collector. January 17, 1921.

9912 (W 199 F). Arrondissement of Las Cahobas, trail from Belladère to Savanette, north slope of mountains about 7 kilometers southwest of Belladère, altitude 460 meters above sea level. W. P. Woodring, collector. January 13, 1921.

Miocene fossils from Central Plain (Madame Joie formation).

Species.	Hinche.			Las Cahobas.		
	9720	9937	9938	9933	9784	9912
Corals:						
Orbicella canalis Vaughan	×	×	....	....	....	....
Orbicella altissima Duncan ?	....	....	×	....	....	....
Mollusca:						
Pteropoda:						
Styliola sp.	....	....	....	×	×	×
Cavolina sp. cf. C. bisulcata (Gabb)	....	....	....	....	...	×
Gastropoda:						
Bullaria ? sp	....	....	....	×	×	....
Natica ? sp	....	....	....	....	×	....
Pelecypoda:						
Limopsis sp.	....	....	....	×	....	....
Bathyarca sp. cf. B. hendersoni Dall	....	....	....	....	×	....

THOMONDE FORMATION AND MAÏSSADE TONGUE.

The name Thomonde "beds," derived from the name of the town of Thomonde, was given by Jones[1] to the rocks overlying the Madame Joie formation. The type locality is in the vicinity of Thomonde. In the southeastern part of the plain the Thomonde formation crops out at the foot of the mountains. The width of the outcrop increases as the rocks arch over the crests of the plunging anticlines. The outcrop is wider along its northeast edge, because the formation is thicker there and the structure is different. In the entire northwestern part of the plain the Thomonde formation lies at the surface or is covered only by a thin layer of Pliocene or Quaternary stream deposits.

The Thomonde formation conformably overlies the Madame Joie formation, which along the northeast edge of the plain seems to be completely overlapped by it.

Southeastern part.—Along the west and south edges of the southeastern part of the plain the Thomonde formation consists principally of soft rocks, and its outcrop is marked by a depression along the foot of the mountains and on the plunging anticlines. At the type locality the formation is about 400 meters thick and consists principally of siltstone, either sandy or clayey. There are a few thin beds of sandstone near the base and a few beds of coarser sandstone and conglomerate near the top. The siltstone is similar to the siltstone in the lower part of the Madame Joie formation. The unweathered rock is bluish gray, but surfaces that have been oxidized and leached are rusty brown or yellowish brown. The upper part of the formation is well exposed on the south limb of the Thomonde anticline on the slope leading down to Rivière Thomonde, along the trail from Las Cahobas to Thomonde, and on the north limb along the trail from Thomonde to Thomassique.

Good exposures of the upper part of the formation can be seen on Rivière Thomonde below Thomonde. Numerous collections of fossils were obtained from the beds in the uppermost 100 meters of the Thomonde formation, on the crest and limbs of the Thomonde anticline. They are listed on pages 178-190. Detailed descriptions of the localities are given on pages 175, 177 (stations 9782, 9781, 9780, 9929, 9778, 9779, 9791, and 9785). The best fossils were collected on Rivière Thomonde at station 9782. Along the trails where the beds lie above the level of ground water the shell substance of many specimens has been removed by leaching, leaving only casts and impressions. Casts are particularly common in the porous beds at the top of the formation. The lower part of the Thomonde formation on the Thomonde anticline also consists of bluish-gray siltstone but contains only a few fossils. (See list, pp. 178-190, station 9935.)

The middle part was examined on Rivière l'Ayaye, on the crest of the l'Ayaye anticline along the west edge of the plain. The following section

[1] Jones, W. F., op. cit., p. 736, 1918.

is exposed in the lower third of the first high bluff on the left bank of Rivière l'Ayaye above its mouth:

Section of beds in middle part of Thomonde formation on Rivière l'Ayaye (station 9907).

	Est. thickness in meters.
7. Siltstone, bluish	3
6. Siltstone, sandy; fragments of lignitized wood	1
5. Siltstone, bluish	2
4. Siltstone, sandy (lens)	.5
3. Siltstone, yellowish	1
2. Siltstone, sandy	.5
1. Siltstone, bluish	.5
Stream level.	
	8.5

The fossils from this locality (station 9907; see list, pp. 178-190) were collected from the beds given in the section and higher beds, some of the best specimens being obtained from loose blocks at the foot of the bluff, which is about 25 meters high. The fossils listed on pages 178-190 (station 9908), were collected from a layer in sandy siltstone in the next bluff on the left bank downstream.

The Thomonde formation is not very well exposed along the south edge of the plain near Las Cahobas. At the exposures examined it consists of sandy and clayey siltstone. A collection of fossils (station 9904; see list, pp. 178-190), indicates that the beds were laid down in relatively deep water. On the east side of the road from Mirebalais to Las Cahobas and immediately north of the small stream at the foot of the mountains, on the north side of the gap, soft sandy and clayey beds in the Thomonde formation strike N. 30° W. and dip 32° NE. At the same locality but on the west side of the road, there is finely laminated buff or yellowish clay, from which the plants and fish listed on page 206 (station 7544) were collected. The clay dips about 5° SW. At the top of the hill about 60 meters farther northeast, toward Las Cahobas, similar clay seems to rest unconformably on beds belonging to the Thomonde formation. The plants are strand plants, and one of the species was obtained from beds of known Miocene age in the Artibonite Valley (see p. 215), but the fish belongs to a fresh-water genus. The clay can hardly belong to the Thomonde formation because of its stratigraphic relations and because the Thomonde formation not far distant along the strike carries a relatively deep-water fauna. It may represent some part of the Miocene series not known elsewhere in the Central Plain. Its stratigraphic relations led to the supposition in the field that it was of Pliocene age, but overwhelming evidence shows that the sea withdrew from the area now embraced by the Central Plain before Pliocene time. It is unfortunate that the age of these beds is not known, as they furnished the largest collection of fossil plants obtained in the Republic.

On the Belladère anticline, at the southeastern extremity of the plain, the Thomonde formation was seen only on the north limb along the trail from Las Cahobas to Belladère and its prolongation eastward beyond Belladère toward Commendador. Siltstone and thin beds of sandstone dip from 12° to 24° almost due north.

Along the northeast side of the plain the lithology of the Thomonde formation is entirely different, for in this region it consists largely of coarse detrital sediments, principally conglomerate and coarse sandstone. (See Pl. XIV, *A*.) Most of the coarse sediments are of nonmarine origin and are apparently delta and flood-plain deposits laid down along the old landmass that stretched along this side of the plain during Miocene time. Toward the southwest, under the cover of younger rocks, the coarse nonmarine sediments probably interfinger with the fine-grained marine sedi-

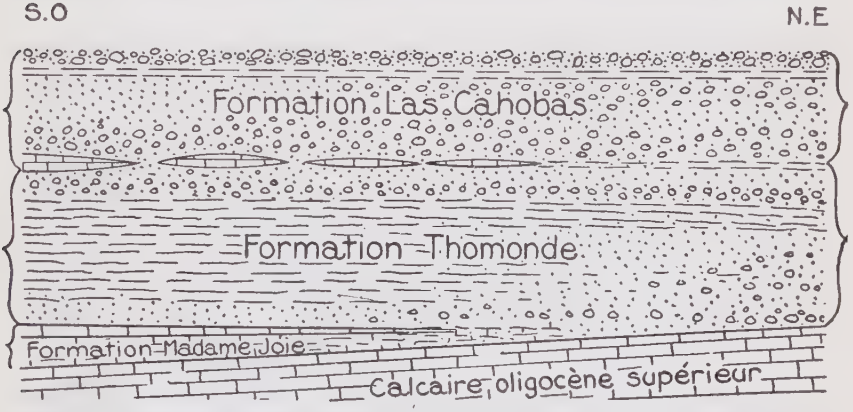


FIGURE 10.—Diagram showing lateral change in lithology of the Miocene rocks of the Central Plain and the transgressive overlap of the Thomonde formation.

The total thickness of the Las Cahobas formation is not shown.

ments that crop out along the west and south edges of the plain, as is shown in Figure 10. Thin wedges of fine-grained marine sediments extend northeastward into this area of coarse rocks, indicating continuous movements of the strand and breaks in the deposition of sediments along the margin of the sea. These marine wedges contain typical Thomonde fossils. The largest collections made and the largest collections from the entire Thomonde formation were obtained on Ravine Roche Salée at the crossing of the trail from Hinche to Thomassique, about 3 kilometers southeast of Los Palos. (See lists, pp. 178-190; stations 9945 and 9946.) Many of the shells are closely packed in pockets, which indicates sorting by waves or currents.

Fossils typical of the upper part of the Thomonde formation were collected from sandy siltstone less than half a kilometer north of Thomassique on the trail to Cerca-la-Source. (See list, pp. 178-190; station 9947.)

Countless specimens of *Orthaulax aguadillensis* are weathered out of or partly embedded in the rock at this locality. Most of the specimens are casts, except *Orthaulax, Ostrea,* and *Pecten,* as is common in beds above the level of ground water.

Fossils similar to those in the middle part of the Thomonde formation on the west side of the plain were collected on the same trail at the first crossing of Rivière Honde. (See list, pp. 178-190; station 9948.) The Thomonde formation, which is clearly transgressive, probably overlaps the coarse marginal deposits of the Madame Joie formation on this side of the plain, as is shown on the map (Pl. XXXVI) and in Figure 10.

Beds of fine sandstone and siltstone that contain no marine fossils and that are considered nonmarine are interbedded with the conglomerates and coarse sandstones, but they are buff, reddish, or greenish. Most of the marine beds are bluish gray, but some of them are greenish. Toward the mountains the conglomerates contain an increasing proportion of disk-shaped pebbles of argillite derived from the area of argillite near Cercala-Source. Conditions seem to be favorable for a quantitative study of the gradual elimination of pebbles of argillite in terms of increasing distance from the landmass.

Northwestern part.—In the northwestern part of the plain, northwest of Hinche, the stratigraphic relations of different parts of the Thomonde formation are more complex, and the relations presented in this report are based primarily on a study of the fossil mollusks.

In this part of the plain the lower part of the Thomonde formation consists of siltstone and thin beds of fine-grained sandstone resembling the lower part of the formation in the southeastern part of the plain and containing the same fauna. This part of the formation is about 250 meters thick. It crops out along the foot of the mountains immediately above the Madame Joie formation and on the Fond Bleu dome. Fossils were collected from it on the south limb of the Fond Bleu dome (station 9719) and northeast of Madame Joie near Rivière Blanche (station 9939; see lists on pp. 178-190).

The middle part of the formation, which is about 100 meters thick, consists principally of conglomerate and coarse sandstone resembling those in the overlying Las Cahobas formation. These beds form the pine-covered "rim rock" around the Fond Bleu dome. Rivière Blanche flows across them in a short, narrow gorge. They probably represent some of the beds in the middle part of the Thomonde formation as developed in the southeastern part of the plain.

Above these conglomerates and sandstones lies a series of lignite-bearing beds to which Jones[1] gave the name Maissade "beds," derived from the name of the town of Maïssade. Extensive collections of fossils were made from this series of beds at exposures on Rivière Fond Gras and Rivière

[1] Jones, W. F., op. cit., p. 739, 1918.

A. THOMONDE FORMATION ON RIVIÈRE HONDE, ON THE NORTHEAST SIDE OF THE CENTRAL PLAIN.

B. LAS CAHOBAS FORMATION NEAR LAS CAHOBAS, ON THE SOUTH SIDE OF THE CENTRAL PLAIN.

C. MIOCENE MARL NEAR LA CHAPELLE.

Blanche (or Rio Blanco), northeastward-flowing tributaries of Rivière Canot northwest of Maïssade. These collections show that the Maïssade "beds" consist of a remarkable alternation of beds, some of which contain a marine fauna, others a mixture of marine and brackish-water faunas, and others a brackish-water fauna. The collections are listed on pages 194-197 (stations 9717, 9713, 9714, 9715, 9722, 9726, 9711, 9716, 9723, 9724, 9725, 9727, 9728, 9729, 9732, 9733, 9710, 9718, 9712, 9730, 9731). The beds containing the marine mollusks occur in the lower and middle parts of the lignite-bearing series. The largest marine faunule was collected at the northwest end of the Fond Bleu dome, on Rivière Fond Bleu, from beds near the base of the series (station 9717). These fossils are typical of the middle part of the Thomonde formation in the southeastern part, and show that the lower and middle parts of the Maïssade "beds" are a coastal-swamp facies of the middle part of the Thomonde formation. The series of lignite-bearing rocks is therefore called the Maïssade tongue

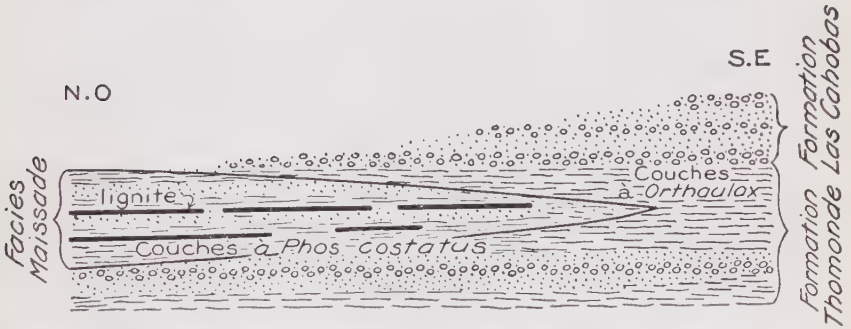


FIGURE 11.—Diagram showing stratigraphic relations of the Maïssade tongue of the Thomonde formation.

of the Thomonde formation. The fauna of the upper part of the Thomonde formation was not discovered in this part of the plain, and the higher beds of the Maïssade tongue, which are wholly nonmarine, seem to be the equivalent of the upper part of the Thomonde. Toward the southeast the Maïssade tongue probably interfingers with other parts of the Thomonde formation, but the outcrops were not traced. This inferred relation is shown on Plate XXXVI and in Figure 11.

Beds near the base of the Maïssade tongue are exposed in roadcuts along the road from Maïssade to Hinche, up the hill south of the crossing of Rivière Frio. They consist of beds of sandy siltstone containing crystals of gypsum and thin beds of coarse, pebbly sandstone and dip 45° NE. Near the top of the hill lies a bed of carbonaceous clay 82 centimeters thick. Farther to the south and southeast there are soft cross-bedded sandstone containing *Ostrea* and *Scapharca* (station 9926) and conglomerate. These beds probably lie at the top of the series of coarse sandstones and conglomerates below the Maïssade tongue.

The Maïssade tongue is about 200 meters thick. The lowermost beds, about 50 meters thick, consist of siltstone, sandstone, and clay. In this part of the formation some of the clay is carbonaceous. Higher beds contain more carbonaceous material, and most of the beds of lignite, which are described on pages 481-483, occur at about the middle of the formation. The uppermost beds are entirely nonmarine and consist of sandstone, clay, and siltstone, most of which are colored in shades of red and green. A conspicuous bed of red clay containing flakes of gypsum extends across the road from Maïssade to St.-Michel de l'Atalaye, about 200 meters north of the crossing of Ravine Reparadère, near Maïssade.

The following sections of the Maïssade tongue show the rapid alternation of beds. The region in which they were deposited was a coastal swamp that was repeatedly invaded by the sea, but finally the sea withdrew. The carbonaceous material in the beds of carbonaceous shale and lignite probably represents débris of coastal-swamp vegetation, but no determinable plants were obtained.

The Maïssade tongue is well exposed on Rivière Blanche. The following sections of beds about 20 meters above the base of the tongue was measured in the first bluff on the left bank of Rivière Blanche below the gorge formed by the underlying conglomerates and sandstones:

Section of lower part of Maïssade tongue on Rivière Blanche.

	Meters.
7. Clay, sandy	.50
6. Clay, black, carbonaceous	.11
5. Clay, sandy, brown; fragments of brackish-water mollusks	.20
4. Siltstone, sandy, bluish; fragments of marine mollusks	.50
3. Oyster bed	1.75
2. Siltstone, sandy, bluish	10
1. Siltstone, sandy, fragments of marine mollusks	2
	15.06

Beds in the following section are exposed in the first long bluff on the right bank of Rivière Blanche below the gorge. The base of this section is about 75 meters higher stratigraphically than the top of the preceding section. At this locality the beds dip northeastward 45° to 58°.

Section of middle part of Maïssade tongue on Rivière Blanche.

	Meters.
47. Siltstone, bluish, marine fauna; station 9722	5.40
46. Siltstone, mixed marine and brackish-water fauna; station 9723	.25
45. Siltstone, bluish gray, sandy; small fragile bivalves	.80
44. Siltstone, gray, mixed marine and brackish-water fauna; station 9724	.60
43. Siltstone, gray; mixed marine and brackish-water fauna; station 9725	.35

		Meters.
42.	Siltstone, dark gray, slightly carbonaceous	.45
41.	Lignite, dirty; streaks of pure lignite	.30
	Lignite	.13
	Lignite, dirty	.05
40.	Siltstone, dark gray, carbonaceous; thin streaks of dirty lignite	.60
39.	Siltstone, gray	.16
38.	Siltstone, gray; streaks of dirty lignite	.55
37.	Not exposed	3
36.	Siltstone, bluish gray; marine fauna; station 9726	3
35.	Siltstone, gray; oyster bed	.35
34.	Siltstone, gray; mixed marine and brackish-water fauna; station 9727	.65
33.	Siltstone, gray, thin irregular seams of lignite at base	.13
32.	Siltstone, gray; mixed marine and brackish fauna; nests of *Scapharca;* station 9728	1.40
31.	Siltstone, gray; oyster bed	.20
30.	Siltstone, bluish gray; carries *Potamides*	2.50
29.	Siltstone, gray; extends as ledge across stream; mixed marine and brackish-water fauna; masses of *Scapharca chiriquiensis;* station 9729	.50
28.	Siltstone, bluish gray	1.75
27.	Clay, carbonaceous	.15
	Lignite	.20
	Lignite; two sandy partings that contain fragments of *Mytilopsis*	.60
	Lignite, dirty	.30
26.	Clay, greenish blue	5
25.	Siltstone; layers of hard sandy material and softer clayey material	1.14
24.	Clay, black, carbonaceous; a thin band contains brackish-water mollusks; station 9730	.07
23.	Siltstone, sandy, dark gray	.27
22.	Clay, black, carbonaceous; streaks of sandy siltstone	.80
21.	Siltstone, slightly carbonaceous; brackish-water fauna; station 9731	.80
20.	Clay, dark gray to black; carries *Potamides*	1
19.	Siltstone, greenish blue	1.25
18.	Oyster bed	.10
17.	Siltstone, greenish blue; not well exposed	4
16.	Oyster bed	.50
15.	Siltstone, bluish green; carries *Scapharca*	.35
14.	Clay, carbonaceous	.45
13.	Sandstone; thin seams of lignite	1.15
12.	Lignite, very dirty	.75
11.	Siltstone, dark gray; seams of carbonaceous clay	4
10.	Lignite, dirty	.06
	Lignite	.48
9.	Siltstone, sandy, dark gray	.32
8.	Lignite, dirty	.05
7.	Siltstone, bluish gray	3
6.	Siltstone, gray; mixed marine and brackish-water fauna; station 9732	3

	Meters.
5. Oyster bed	.50
4. Siltstone, bluish; carries *Scapharca*	4
3. Oyster bed	.50
2. Siltstone, dark gray; pieces of carbonaceous material; mixed marine and brackish-water fauna; station 9733	2
1. Siltstone, bluish gray	1
	60.91

The following section of beds in the middle part of the Maïssade tongue was measured at a long bluff on the right bank of Rivière Fond Gras about 2 kilometers above the junction of Rivière Fond Gras and Rivière Canot. The beds dip 70° to 80° NE.

Section of middle part of Maïssade tongue on Rivière Fond Gras.

	Meters.
15. Oyster bed	1
14. Clay, bluish green; mixed marine and brackish-water fauna; station 9711	2
13. Lignite, dirty	.22
12. Siltstone, bluish; brackish-water fauna; station 9712	5
11. Oyster bed	1
10. Siltstone, sandy	3
9. Lignite, dirty	.50
Lignite	.43
8. Siltstone, brackish-water fauna	2
7. Oyster bed	1
6. Siltstone, sandy; marine fauna; station 9713	1.50
5. Lignite	.14
Clay, carbonaceous	.03
Lignite	.06
Lignite, dirty	.07
Clay, carbonaceous	.05
Lignite, dirty	.05
Lignite	.07
Lignite, dirty	.08
Clay, carbonaceous	.12
4. Siltstone, bluish; marine fauna; station 9714	2
3. Siltstone, sandy; marine fauna; station 9715	5
2. Lignite, dirty	.09
1. Clay, carbonaceous; fragments of *Mytilopsis*	.08
	25.49

At a bluff on the right bank of Rivière Frio, about 100 meters above the crossing of the road from Maïssade to Hinche, the following beds are exposed:

Section of beds in middle part of Maïssade tongue on Rivière Frio.

		Meters.
10.	Siltstone, grayish brown; carries *Potamides*.	
9.	Lignite	.17
	Clay, brown, carbonaceous	.43
	Lignite	.14
	Lignite, dirty	.18
	Clay, black, carbonaceous; fragments of mollusks	.55
8.	Siltstone and clay, bluish green	5
7.	Clay, chocolate-brown	.50
6.	Clay, black, carbonaceous; streaks of lignite	.44
5.	Clay, grayish brown	2
4.	Siltstone, bluish green	1
3.	Not exposed	30
2.	Lignite, dirty streaks	2.50
1.	Clay, brown, brackish-water fauna; station 9710	1
		43.91

The upper part of the Maïssade tongue was examined on Rivière Canot below the crossing of the road from Maïssade to St.-Michel de l'Atalaye. It is made up of reddish and greenish siltstone, coarse rusty-brown sandstone, greenish sandstone, and conglomerate containing small pebbles. None of these beds is fossiliferous.

On the northeast side of the northwestern part of the plain the Thomonde formation resembles the middle part of that formation on the southwest side of that part of the plain, but is much thicker and consists principally of conglomerates and coarse sandstones. These beds are similar to those in the Thomonde formation along the northeast side of the southeastern part of the plain, but no marine fossils were found in the northwestern part and the beds there probably consist entirely of flood-plain and delta deposits. They are indistinguishable from similar beds in the Las Cahobas formation, and when the Maïssade beds were named it was supposed that they and the conglomerates underlying the Maïssade tongue on the southeast side of the plain belonged to the Las Cahobas.

Fossils, Thomonde formation.—Large collections of fossils were obtained from the Thomonde formation, which can be divided into three faunal zones corresponding to the lower, middle, and upper parts already described.

Corals are abundant in the middle and upper faunal zones, but none of them are of reef facies. The Recent species *Solenastrea bournoni* Milne-Edwards and Haime and *Siderastrea siderea* (Ellis and Solander) give the fauna a modern aspect. Several species of *Stylophora* and a new species of *Asterosmilia* are common in the middle faunal zone at stations 9907 and 9908 on Rivière l'Ayaye. *Stylophora minor* Duncan, collected from the middle faunal zone at station 9948, is characteristic of younger beds (Gurabo formation and Mao Adentro limestone) in the northern part of the Dominican Republic. *Antillia dubia* Duncan, found in the upper

faunal zone, is known also only from younger beds (Cercado and Gurabo formations) in the Dominican Republic. A new species of *Psammocora* was obtained from Miocene rocks in the Arbre Plain. The same species has been obtained also from the lower Miocene rocks of Trinidad. The middle part of the formation near Las Cahobas contains a *Deltocyathus* similar to the Miocene and Recent relatively deep-water species *D. italicus* (Michelotti), indicating that along the south edge of the plain the formation was deposited in deeper water than in the central and northern parts.

Abundance of mollusks is a characteristic feature of the Miocene deposits of the West Indies and regions near by where these deposits consist of detrital rocks. Large faunas have been obtained in the Dominican Republic, Jamaica, Trinidad, Colombia, Panama, and Costa Rica. In Cuba and Porto Rico, where rocks of the same age are more calcareous, mollusks are less abundant and poorly preserved. The mollusks of the Cercado and Gurabo formations of the Dominican Republic are well known through Maury's [1] work, although many additional species were obtained during the reconnaissance made under the supervision of the United States Geological Survey.[2] About 500 species are known from the Cercado formation and about 400 from the Gurabo formation. A description by Woodring of the Bowden fauna of Jamaica, comprising almost 600 species, is awaiting publication by the Carnegie Institution of Washington. Olsson [3] has recently described more than 300 Miocene species from Costa Rica.

The total molluscan fauna of the Thomonde formation, including the Maïssade tongue, numbers more than 350 species. The upper faunal zone, and probably the whole formation, is the equivalent of the Baitoa formation of the Dominican Republic. As only 60 species were obtained from the Baitoa formation, the Thomonde fauna fills a gap in the succession of Miocene faunas of the West Indies.

The lower faunal zone contains only a few mollusks, principally pteropods of the genera *Styliola* and *Cavolina,* indicating clear and relatively deep water and resembling the small faunule in the lower part of the underlying Madame Joie formation.

The middle and upper faunal zones contain a rich shoal-water fauna. Some of the characteristic Thomonde mollusks are shown on Plate XV. *Orthaulax aguadillensis* Maury (Pl. XV, fig. 3) is the most striking and one of the most common of the mollusks in the upper faunal zone. Interesting specimens of this species have been described by Woodring.[4] It was originally described from beds of upper Oligocene age in Porto

[1] Maury, C. J., Santo Domingo type sections and fossils: Bull. Am. Paleontology, vol. 5, pp. 165-459, pls. 27-68, 1917.

[2] See lists in A geological reconnaissance of the Dominican Republic: Dominican Rep. Geol. Survey Mem., vol. 1, pp. 116-129, 137-151, 1921.

[3] Olsson, A. A., The Miocene of northern Costa Rica: Bull. Am. Paleontology, vol. 9, pp. 179-418, pls. 4-35, 1922.

[4] Woodring, W. P., Tertiary mollusks of the genus *Orthaulax* from the Republic of Haiti, Porto Rico, and Cuba: U. S. Nat. Mus. Proc., vol. 64, art. 1, 12 pp., 2 pls. 1923.

Rico but has been found also in deposits of the same age (Cevicos limestone) in the Dominican Republic and in deposits of Miocene age in Porto Rico and the Dominican Republic.[1] Perhaps the most curious Thomonde mollusk is a *Terebra*-like columbellid which is considered a new subspecies of *Strombinella acuformis* Dall, described from beds of Miocene age near Potrero, Province of Santiago, Dominican Republic.[2] Many specimens of this mollusk were collected from the upper faunal zone at stations 9945 and 9946.

The following are the most striking species confined to the upper faunal zone: *Conus veatchi* Olsson (Pl. XV, figs. 1, 2), *Conus* n. sp. (also from Baitoa formation), *Xancus rex* Pilsbry and Johnson, *Phos semicostatus* Gabb (Pl. XV, figs. 6, 7), *Strombinella acuformis* Dall n. subsp., *Orthaulax aguadillensis* Maury (Pl. XV, fig. 3), and *Scapharca corcupidonis* Maury n. subsp. Most of these and other species are identical with or similar to species from the Baitoa formation. Other species are similar to species from the Cercado formation. Many species are similar to species from the Chipola marl of Florida, particularly some Pleurotomids, Marginellas, and Fusimitras. A few species are similar to those in the younger Gurabo formation and the Bowden marl.

The Thomonde formation apparently is the equivalent of part of the Yaque group of the San Juan Valley and the valley of Rio Yaque del Sur in the Dominican Republic, although except for *Orthaulax aguadillensis* the molluscan faunas are not very similar. It is regarded as of Burdigalian age, probably middle Burdigalian, although no direct comparison has yet been made with European faunas.

Stations in Central Plain, Thomonde formation (Miocene).

9945 (W 320 F). Arrondissement of Hinche, trail from Hinche to Thomassique, left bank of Ravine Roche Salée at crossing about 3 kilometers southeast of Los Palos, upper part of Thomonde formation. W. P. Woodring, collector. March 12, 1921.

9946 (W 321 F). Arrondissement of Hinche, trail from Hinche to Thomassique, right bank of Ravine Roche Salée at crossing about 3 kilometers southeast of Las Palos, upper part of Thomonde formation, 1 meter higher stratigraphically than 9945. W. P. Woodring, collector. March 12, 1921.

9947 (W 322 F). Arrondissement of Hinche, trail from Thomassique to Cercala-Source, 0.5. kilometer north-northeast of Thomassique; upper part of Thomonde formation. W. P. Woodring, collector. March 13, 1921.

9782 (W 211 F). Arrondissement of Las Cahobas, crest of Thomonde anticline, left bank of Rivière Thomonde, about 4 kilometers east-southeast of Thomonde; upper part of Thomonde formation. W. P. Woodring, collector. January 16, 1921.

9779 (W 208 F). Arrondissement of Las Cahobas, south limb of Thomonde anticline, on trail from Las Cahobas to Thomonde, about 2 kilometers south-southeast of Thomonde, at an altitude of 380 meters above sea level; upper part of Thomonde formation. W. P. Woodring, collector. January 15, 1921.

[1] Cooke, C. W., *Orthaulax*, a Tertiary guide fossil: U. S. Geol. Survey Prof. Paper 129, pp. 25, 30-31; pl. 4, figs. 2-6; pl. 5, figs. 1a, 1b, 1921.

[2] Guppy, R. J., and Dall, W. H., Descriptions of Tertiary fossils from the Antillean region: U. S. Nat. Mus. Proc., vol. 19, p. 312, pl. 29, fig. 6, 1896.

PLATE XV.

SOME CHARACTERISTIC MOLLUSKS OF THE THOMONDE FORMATION.

FIGURES 1, 2. *Conus veatchi* Olsson. Two specimens from the same locality, × 1. U. S. G. S. station 9782. U. S. N. M. catalogue No. 350578.

FIGURE 3. *Orthaulax aguadillensis* Maury. View of small specimen showing sculpture and apertural callus, × 1. U. S. G. S. station 9945. U. S. N. M. catalogue No. 350577.

FIGURES 4, 5. *Phos costatus* Gabb. Apertural and dorsal views of same specimens, × 1. U. S. G. S. station 9945. U. S. N. M. catalogue No. 350574.

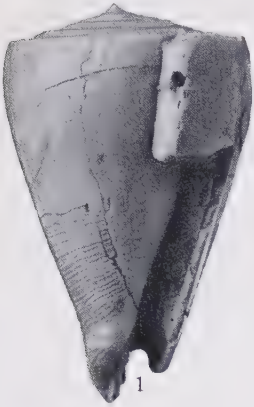
FIGURES 6, 7. *Phos semicostatus* Gabb. Apertural and dorsal views of the same specimen, × 1. U. S. G. S. station 9908. U. S. N. M. catalogue No. 350575.

FIGURES 8, 9. *Cymia henekeni* Maury. Apertural and dorsal views of same specimen, × 1. U. S. G. S. station 9946. U. S. N. M. catalogue No. 350579.

FIGURES 10, 11. *Potamides cahobasensis* Pilsbry. U. S. G. S. station 9908. U. S. N. M. catalogue No. 350576.

Fig. 10. Adult specimen, × 1.

Fig. 11. Young specimen, × 2, showing sculpture of early whorls.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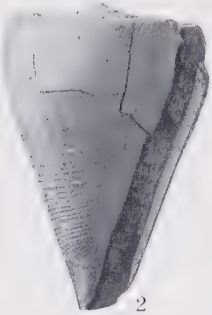
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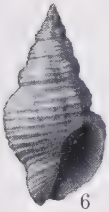
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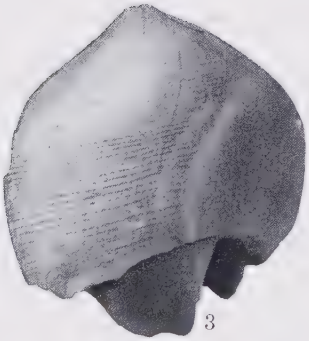
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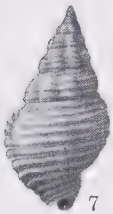
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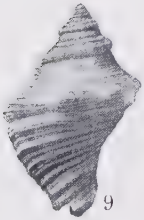
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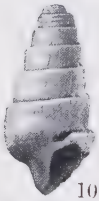
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x 2

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CHARACTERISTIC MOLLUSKS OF THE THOMONDE FORMATION.

9791 (W 315 F). Arrondissement of Las Cahobas, same locality as 9779. T. W. Vaughan and W. P. Woodring, collectors. March 1, 1921.

9778 (W 207 F). Arrondissement of Las Cahobas, south limb of Thomonde anticline, trail from Las Cahobas to Thomonde, about 2.5 kilometers south-southeast of Thomonde, just north of ridge formed by base of Las Cahobas formation, top of Thomonde formation. W. P. Woodring, collector. January 15, 1921.

9785 (W 214 F). Arrondissement of Las Cahobas, south limb of Thomonde anticline, trail from Thomonde to Mirebalais, about 7 kilometers southwest of Thomonde, altitude 395 meters above sea level, upper part of Thomonde formation. W. P. Woodring, collector. January 17, 1921.

9780 (W 209 F). Arrondissement of Las Cahobas, north limb of Thomonde anticline, trail from Thomonde to Thomassique, about 2.5 kilometers northeast of Thomonde, just south of ridge formed by base of Las Cahobas formation, top of Thomonde formation. W. P. Woodring, collector. January 16, 1921.

9781 (W 210 F). Arrondissement of Las Cahobas, north limb of Thomonde anticline about 2.8 kilometers east-northeast of Thomonde, upper part of Thomonde formation. W. P. Woodring, collector. January 16, 1921.

9929 (W 235 F). Arrondissement of Las Cahobas, trail from Hinche to Thomonde, ridge formed by base of Las Cahobas formation about 4 kilometers north-northwest of Thomonde, top of Thomonde formation. W. P. Woodring, collector. January 26, 1921.

9907 (W 190 F). Arrondissement of Las Cahobas, first high bluff on left bank of Rivière l'Ayaye above mouth, about a kilometer above trail crossing near mouth, altitude 185 meters above sea level, middle part of Thomonde formation. W. P. Woodring, collector. January 10, 1921.

9908 (W 191 F). Arrondissement of Las Cahobas, low bluff on left bank of Rivière l'Ayaye, about 0.8 kilometer above trail crossing near mouth, altitude 175 meters above sea level, middle part of Thomonde formation. W. P. Woodring, collector. January 10, 1921.

9926 (W 231 F). Arrondissement of Hinche, road from Maïssade to Hinche, about 3.5 kilometers southeast of Maïssade, altitude 330 meters above sea level, middle part of Thomonde formation, or Maïssade tongue. W. P. Woodring, collector. January 25, 1921.

9948 (W 323 F). Arrondissement of Hinche, trail from Thomassique to Cercala-Source, first crossing of Rivière Honde, middle or lower part of Thomonde formation. W. P. Woodring, collector. March 13, 1921.

9935 (W 243 F). Arrondissement of Las Cahobas, north limb of Thomonde anticline, left bank of Rivière Blanche, about 2.5 kilometers northwest of Thomonde, altitude 310 meters above sea level, lower part of Thomonde formation. W. P. Woodring, collector. January 29, 1921.

9904 (W 186 F). Arrondissement of Las Cahobas, trail from Las Cahobas to Petit-Fond, about 2 kilometers northwest of Las Cahobas, altitude 180 meters above sea level, lower or middle part of Thomonde formation. W. P. Woodring, collector. January 9, 1921.

9719 (W 256 F). Arrondissement of Hinche, west limb of Fond Bleu dome, trail from Maïssade to Madame Joie, about 6 kilometers west of Maïssade, altitude 310 meters above sea level, lower part of Thomonde formation. W. P. Woodring, collector. February 3, 1021.

9939 (W 261 F). Arrondissement of Marmelade, trail from Madame Joie to Rivière Blanche, about 3 kilometers southeast of Rivière Blanche, lower part of Thomonde formation. W. P. Woodring, collector. February 5, 1921.

Miocene fossils from Thomonde formation in Central Plain.

Species.	Upper zone.											Middle zone.				Lower zone.			
	Hinche.			Las Cahobas.										Hinche.		Las Cahobas.	Hinche.	Marmelade.	Las Cahobas.
	9945	9946	9947	9782	9779	9791	9780	9781	9785	9929	9778	9907	9908	9926	9948	9935	9719	9939	9904
Foraminifera:																			
Homotrema sp.	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Sorites sp. cf. S. americana (Cushman)	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Orbiculina sp.	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....
Corals:																			
Deltocyathus sp. cf. D. italicus (Michelotti)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×
Paracyathus ? sp.	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Stylophora minor Duncan	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....
Stylophora n. sp.	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Stylophora sp. a	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Stylophora sp. b	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Stylophora sp. c	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Stylophora sp. d	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Asterosmilia n. sp.	....	....	....	×	....	....	....	....	×	....	....	×	×	....	....	....	....	....	....
Antillia dubia (Duncan)	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Antillia sp., apparently new	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Solenastrea bournoni Milne-Edwards and Haime	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Siderastrea siderea (Ellis and Solander)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....
Psammocora n. sp. b, also from Miocene of Trinidad	×	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Porites sp. aff. P. furcata Lamarck	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Porites sp., apparently new	×	×	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Porites sp.	...	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Porites sp. indet.	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Goniopora sp. cf. G. jacobiana Vaughan	×	....	×	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....

Bryozoa:																				
Cupuladria canariensis Busk	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Callopora dumerillii Savigny-Audouin	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Mamillopora tuberosa Canu and Bassler	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Metrarabdotos sp.	×	×	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Mollusca:																				
Pteropoda:																				
Styliola sp.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	×	
Cavolina sp.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	
Gastropoda:																				
Actaeon ? sp.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....
Acteocina n. sp. a cf. A. subbullata Pilsbry and Johnson	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....
Acteocina n. sp. b, also from Cercado formation of Dominican Republic	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Acteocina sp.	×	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Cylichnella n. sp. a cf. C. trictumtritonis Maury	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Cylichnina n. sp. a cf. C. chipolana (Dall)	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Retusa sp. cf. R. fossilis Pilsbry and Johnson	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Volvula sp. cf. V. cylindrica Gabb	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ringicula n. sp. a cf. R. semilinata Dall	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Bullaria paupercula (Sowerby) ?	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Bullaria sp.	×	×	....	....	....	....	....	....	....	....	....	?	×	×	....	....	....	....	....	....
Terebra (Strioterebra) sp. a cf. T. (S.) berlinerae Maury	×	×	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	?	....
Terebra (Strioterebra) sp. b cf. T. (S.) berlinerae Maury	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Terebra (Strioterebra) sp. c cf. T. (S.) cambiarsoi Maury	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Terebra (Strioterebra) sp. d cf. T. (S.) cambiarsoi Maury	×	×	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....
Terebra (Strioterebra) sp. e cf. new species from Cercado formation	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Terebra (Strioterebra) sp.	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Conus veatchi Olsson, also from Baitoa formation of Dominican Republic	×	×	....	×	×	×	....	....	....	×	×	....	....	×	....	×	....	....	....	....
Conus sp. a cf. C. furvoides brachys Pilsbry and Johnson	....	....	....	....	....	....	....	....	....	....	....	×	×	....	×	....	....	....	....	....
Conus n. sp. a cf. C. williamgabbi Maury	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Conus sp. b cf. new species from Cercado formation	×	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Conus sp. c cf. C. burckhardti Böse	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Conus n. sp. b, also from Baitoa formation	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Conus sp. d cf. C. haitensis Sowerby	....	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Surcula (Pleurofusia) sp.	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

Miocene fossils from Thomonde formation in Central Plain—Continued.

Species.	Upper zone.											Middle zone.		Lower zone.					
	Hinche.			Las Cahobas.								Hinche.		Las Cahobas.		Hinche.		Marmelade.	Las Cahobas.
	9945	9946	9947	9782	9779	9791	9780	9781	9785	9929	9778	9907	9908	9926	9948	9935	9719	9939	9904
Surcula (Pleurofusia) sp. cf. S. (P.) paraservata Gardner (Mss.)	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Turris (Pleuroliria) sp. a cf. new species from Cercado formation	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Turris (Pleuroliria) sp. b cf. T. (P.) barretti (Guppy)	....	....	....	×	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
"Drillia" henekeni (Sowerby)	×	×	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
"Drillia" sp. a cf. D. dorsuosa Pilsbry and Johnson	×	×	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
"Drillia" sp. b cf. new species from Cercado formation	×	×	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
"Drillia" sp. c cf. new species from Cercado formation	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
"Drillia" sp. d cf. D. foveolata Pilsbry and Johnson	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
"Drillia" n. sp. a cf. D. jamaicensis (Guppy)	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
"Drillia" maonisriparum Maury	....	....	....	?	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
"Drillia" n. sp. b cf. D. calligona Maury	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
"Drillia" sp. e cf. D. winchesterae Pilsbry and Johnson	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
"Drillia" sp. f cf. D. venusta (Sowerby)	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
"Drillia" n. sp. c	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
"Drillia" n. sp. d	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
"Drillia" n. sp. e	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....
"Drillia" sp. g	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
"Mangilia" sp. a cf. M. ramondi Maury	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
"Mangilia" sp. b cf. M. psila Bush	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
"Mangilia" sp. c cf. unnamed Cercado sp	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
"Mangilia" sp. d cf. unnamed Cercado sp	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
"Mangilia" sp. e cf. unnamed Gurabo sp	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

"Mangilia" sp. f	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
"Mangilia" sp. g	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
"Mangilia" sp. h	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
"Mangilia" sp. i	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
"Mangilia" sp. j	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....
"Cythara" sp. a cf. C. cercadica Maury	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
"Cythara" sp. b cf. C. mucronata Guppy	×	....	....	....	....	....	....	....	....	....	....	×	?	....	....	....	....	....	....	....
"Cythara" sp. c	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
"Cythara" sp. d	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
"Cythara" sp. e cf. C. gibba Guppy	×	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Glyphostoma sp. cf. G. dentifera Gabb	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Microdrillia sp.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....
Cancellaria n. sp. cf. C. rowelli Dall, also from Baitoa formation	×	×	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Oliva n. sp. cf. O. gatunensis Toula, also from Baitoa formation	×	×	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Oliva sp. a cf. O. dimidiata Pilsbry and Johnson	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Oliva sp. b cf. O. cylindrica Sowerby	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Olivella (Lamprodroma) n. sp. a cf. O. muticoides Gabb	×	×	....	?	....	....	....	....	....	....	....	....	....	....	....	?	....	....	....	....
Olivella (Lamprodroma) n. sp. b cf. O. indivisa Guppy	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Olivella (Lamprodroma) sp. a	....	....	....	....	....	....	....	....	....	....	....	×	×	....	×	....	....	....	....	....
Marginella nugax Pilsbry and Johnson	×	×	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Marginella n. sp. a cf. M. maoensis Maury	×	×	....	×	....	....	....	....	....	....	....	×	?	....	....	....	....	....	....	....
Marginella n. sp. b cf. unnamed Baitoa sp	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Marginella n. sp. c cf. M. oryzoides Gardner (Mss.)	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Marginella n. sp. d cf. M. sowerbyi Gabb	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Marginella sp. a cf. M. amina Dall	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Marginella (Gibberula) sp. a cf. M. (G.) cercadensis Maury	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Marginella (Gibberula) sp. b cf. M. (G.) chondra Gardner (Mss.)	×	×	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Closia n. sp. a cf. unnamed Gurabo sp	×	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Mitra (Cancilla) n. sp. a cf. M. (C.) henekeni Sowerby	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Mitra (Cancilla) n. sp. b cf. M. (C.) longa Gabb, also from Baitoa formation	×	×	....	×	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Mitra (Fusimitra) n. sp. c cf. M. (F.) mangilopsis Gardner (Mss.)	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Mitra ? sp	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

Miocene fossils from Thomonde formation in Central Plain—Continued.

Species.	Upper zone.											Middle zone.				Lower zone.			
	Hinche.			Las Cahobas.								Hinche.				Las Cahobas.	Hinche.	Marmelade.	Las Cahobas.
	9945	9946	9947	9782	9779	9791	9780	9781	9785	9929	9778	9907	9908	9926	9948	9935	9719	9939	9904
Mitra ? sp. indet.	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....
Strigatella ? sp.	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Xancus rex Pilsbry and Johnson, also from Baitoa formation	....	....	....	×	×	....	....	....	....	....	?	....	....	....	×	....	....	....	....
Xancus sp. cf. X. praeovoides Maury	....	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Fasciolaria sp. cf. F. kempi Maury	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....
Fasciolaria sp.	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Peristernia sp. cf. P. insula Olsson	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Fusinus ? sp.	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....
Melongena consors (Sowerby)	....	....	×	×	×	....	....	×	....	....	....	×	×	....	....	....	....	....	....
Melongena orthocantha Pilsbry and Johnson	....	....	....	....	....	....	....	....	....	....	....	×	×	....	×	....	....	....	....
Solenosteira n. sp. cf. S. inornata Dall	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Phos costatus Gabb, also from Baitoa formation	×	×	....	....	....	....	....	....	....	....	....	×	×	....	×	....	....	....	....
Phos semicostatus Gabb, also from Baitoa formation	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Phos sp. a cf. P. elegans Guppy	....	....	....	×	....	×	....	....	....	×	....	×	....	....	....	....	....	....	....
Phos sp. b cf. P. chipolanus Dall	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Phos sp. c	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Alectrion cercadensis Maury	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Alectrion n. sp. cf. A. cercadensis Maury	×	×	....	....	....	....	....	....	....	....	....	×	×	....	×	....	....	....	....
Nassarina n. sp.	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Metula sp. cf. M. cancellata Gabb	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Columbella (Conidea) n. sp.	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

Atilia n. sp. cf. unnamed Cercado sp	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Atilia (Columbellopsis) exilis (Gabb)	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Atilia (Columbellopsis) n. sp. a cf. A. (C.) exilis (Gabb)	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Atilia (Columbellopsis) n. sp. b cf. unnamed Cercado and Gurabo sp	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Atilia (Columbellopsis) n. sp. c	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Atilia (Columbellopsis) sp	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Strombina n. sp. a cf. S. caribaea Gabb, also from Baitoa formation	×	×	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Strombina n. sp. c cf. S. cyphonotus Pilsbry and Johnson	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Strombina sp. a	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Strombinella acuformis Dall n. subsp	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Murex sp. a cf. M. messorius Sowerby	×	×	....	×	....	....	....	....	....	....	....	×	×	....	×	....	....	....	....	....
Murex (Phyllonotus) compactus Gabb	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Ocinebra sp.	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Muricidea sp.	×	×	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Typhis sp. cf. T. alatus Sowerby	....	×	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Cymia henekeni Maury, also from Baitoa formation	×	×	....	....	....	....	....	....	....	....	....	?	....	....	....	....	....	....	....	....
Cymia henekeni tectiformis Pilsbry	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Morum sp. cf. M. domingense (Sowerby)	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Malea elliptica Pilsbry and Johnson	....	....	....	×	....	....	....	....	....	?	×	....	....	....	....	....	....	....	....	....
Cypraea n. sp. cf. C. raymondrobertsi Pilsbry	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Cypraea sp. indet.	....	....	....	....	....	....	....	....	....	×	....	×	....	....	....	....	....	....	....	....
Strombus sp. cf. S. proximus Sowerby	×	....	?	×	....	....	×	....	....	×	....	....	....	....	....	....	....	....	....	....
Strombus sp.	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....
Orthaulax aquadillensis Maury	×	×	×	×	×	....	×	×	....	×	×	....	....	....	....	....	....	....	....	....
Cerithium (Vulgocerithium) n. sp. cf. C. (V.) russeli Maury	×	×	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Cerithium (Vulgocerithium) sp.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Cerithium (Ptychocerithium) n. sp. a	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Cerithium (Ptychocerithium) n. sp. b	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Clava alajuela Olsson, also from Baitoa formation	×	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Conocerithium sp.	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Potamides dentilabris (Gabb)	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Potamides n. sp. a cf. P. gastrodon Pilsbry and Johnson	×	×	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Potamides caobasensis Pilsbry	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Cerithidea sp. a	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

Miocene fossils from Thomonde formation in Central Plain—Continued.

Species.	Upper zone.													Middle zone.		Lower zone.			
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	9945	9946	9947	9782	9779	9791	9780	9781	9785	9929	9778	9907	9908	9926	9948	9935	9719	9939	9904
Cerithidea sp. b	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Cerithidea sp. c	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Bittium sp. a	×	×	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Bittium asperoides Gabb	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Bittium sp. b	....	....	....	....	....	....	....	....	....	....	....	×	×	....	×	....	....	....	....
Bittium sp. c	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Bittium sp.	....	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Cerithiopsis sp. a	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Cerithiopsis sp. b	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Cerithiopsis sp. c	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Cerithiopsis sp. d	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Seila sp.	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Triphora sp. a	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Triphora sp. b	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Triphora sp. c	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Alaba sp.	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Modulus n. sp. cf. M. basileus (Guppy)	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Modulus sp.	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Serpulorbis sp.	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Petaloconchus domingensis Sowerby	....	....	....	×	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....
Vermicularia sp. cf. V. spirata (Philippi)	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Turritella calostemma Pilsbry and Brown	×	×	?	×	×	×	?	....	....	×	×	....	....	....	....	....	?	....	....
Turritella sulcigyrata Pilsbry and Johnson	....	....	....	×	....	×	....	....	....	....	×	×	×	....	....	....	....	....	....
Caecum sp. cf. C. annelifer Pilsbry and Johnson	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

Caecum sp.	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Meioceras sp. cf. M. constrictum (Gabb)	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Meioceras n. sp. a	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Hemisinus sp. cf. H. truncatus (Gabb)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Architectonica sp. cf. A. quadriseriata (Sowerby)	....	....	....	×	....	....	....	....	....	....	....	?	....	....	....	....	....	....	....	....
Architectonica stonemanae Maury	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Architectonica sp. a cf. unnamed Cercado sp	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Architectonica sp. b	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Fossarus (Isapis) sp. a	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Rissoina crassilabris (Gabb)	×	×	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Rissoina sp. a cf. R. striatacostata d'Orbigny	×	×	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Rissoina sp. b cf. R. multicostata Adams	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Rissoina sp. c cf. R. sagriana d'Orbigny	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Rissoina sp. d	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Tryonia sp. a	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Tryonia sp. b	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Tryonia sp. c	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Crepidula sp.	×	×	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Crucibulum sp. cf. C. chipolanum Dall	....	....	....	×	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Crucibulum sp. cf. C. piliferum Guppy	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Crucibulum sp.	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Calyptraea sp.	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Calyptraea ? sp.	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Natica sp. cf. N. canrena Linnaeus	×	×	....	×	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Natica sp. a	×	....	....	....	....	....	....	....	....	....	....	....	....	....	?	....	....	....	....	....
Natica sp. b	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....
Natica sp. indet	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....
Natica (Stigmaulax) sp. cf. N. (S.) sulcata Born	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Polinices subclausa (Sowerby)	×	×	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Neverita nereidis Maury	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Amauropsis sp. cf. A. guppyi Gabb	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Amauropsis ? sp.	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....	....
Sinum sp. cf. S. chipolanum Dall	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Sinum sp.	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Epitonium sp. a	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Epitonium sp. b	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Melanella sp. a	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Melanella sp. b	×	×	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....

Miocene fossils from Thomonde formation in Central Plain—Continued.

Species.	Upper zone.											Middle zone.				Lower zone.			
	Hinche.			Las Cahobas.										Hinche.		Las Cahobas.	Hinche.	Marmelade.	Las Cahobas.
	9945	9946	9947	9782	9779	9791	9780	9781	9785	9929	9778	9907	9908	9926	9948	9935	9719	9939	9904
Melanella sp. c	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Melanella sp. d	....	×	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Melanella sp. e	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Strombiformis sp. a	....	×	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....
Strombiformis sp. b	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Pyramidella sp. a	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Pyramidella sp. b	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Pyramidella sp.	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Turbonilla sp. a	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Turbonilla sp. b	....	×	....	....	....	....	....	....	....	....	....	....	?	....	....	....	....	....	....
Turbonilla sp. c	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Turbonilla sp. d	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Turbonilla sp. e	....	....	....	....	....	....	....	....	....	....	....	×	....	....	×	....	....	....	....
Turbonilla sp. f	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Turbonilla sp.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....
Odostomia sp. a	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Odostomia sp. b	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Turbo sp. cf. T. dominicensis Gabb	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Astraea sp.	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Phasianella punctata (Gabb)	×	×	....	×	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Phasianella sp.	×	×	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....
Neritina (Smaragdia) viridimaris Maury	×	×	×	....	....	....	....	....	....	....	....	×	×	....	×	....	....	....	....
Neritina (Puperita) figulopicta Maury	×	×	....	....	....	....	....	....	....	....	....	×	×	....	×	....	....	....	....
Solariella ? sp	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

Liotia sp. a	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Liotia sp. b	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Liotia sp. c	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Liotia sp. d	....	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Circulus pentagona (Gabb)	×	×	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Solariorbis sp.	×	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Teinostoma depressum (Gabb)	×	×	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Teinostoma sp. a	×	×	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Teinostoma sp. b	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Teinostoma sp. c	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....
Pseudorotella sp.	×	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....
Discopsis derbyi Maury n. subsp	×	×	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Fissuridea sp. a	×	....	....	....	....	....	....	....	....	?	....	....	....	....	....	....	....	....	....	....
Fissuridea sp. b	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....
Scaphopoda:																				
Dentalium dissimile Guppy	×	×	....	×	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Dentalium pyrum Pilsbry and Sharp	×	×	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Dentalium sp. group of D. antillarum d'Orbigny	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Dentalium sp.	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Dentalium ? sp	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Cadulus sp. a cf. C. phenax Pilsbry and Sharp	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....
Cadulus sp. b cf. C. colobus Pilsbry and Sharp	×	×	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Cadulus sp. c cf. C. elegantissimus Pilsbry and Sharp	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Cadulus n. sp. cf. C. simrothi Pilsbry and Sharp	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....
Pelecypoda:																				
Nucula tenuisculpta Gabb	×	×	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Leda n. sp. a cf. L. extricata Pilsbry and Johnson	×	×	....	×	....	....	?	....	....	?	....	×	×	....	....	....	....	....	....	....
Leda ? sp	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Arca sp. cf. A. yaquensis Maury	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×
Arca yaquensis Maury n. subsp	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Arca sp. cf. A. bowdenensis Dall	×	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Barbatia sp. cf. B. marylandica (Conrad)	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Barbatia (Acar) sp. cf. B. (A.) domingensis (Lamarck)	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Scapharca tolepia Dall n. subsp., also from Baitoa formation	×	×	....	....	....	....	....	....	....	?	?	....	....	....	×	....	....	....	....	....
Scapharca corcupidonis Maury n. subsp	×	×	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Scapharca sp. a	....	....	....	×	....	×	....	....	....	?	....	....	....	....	....	....	....	....	....	....
Scapharca sp. b cf. S. actinophora Dall	....	....	×	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

Miocene fossils from Thomonde formation in Central Plain—Continued.

Species.	Upper zone.											Middle zone.				Lower zone.			
	Hinche.			Las Cahobas.								Hinche.				Las Cahobas.	Hinche.	Marmelade.	Las Cahobas.
	9945	9946	9947	9782	9779	9791	9780	9781	9785	9929	9778	9907	9908	9926	9948	9935	9719	9939	9904
Scapharca sp. c cf. S. hypomela Dall	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Scapharca sp. d	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....
Scapharca cibaoica Maury n. subsp	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Scapharca sp. e cf. S. golfoyaquensis Maury	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Scapharca sp. f cf. S. halidonata Dall	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....
Scapharca chiriquiensis (Gabb)	....	....	....	....	....	....	....	....	....	....	....	×	×	×	....	....	....	....	....
Scapharca chiriquiensis websteri (Pilsbry)	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Fossularca sp. cf. F. adamsi Dall	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Glycymeris acuticostata (Sowerby) n. subsp	....	....	....	×	....	×	....	....	....	?	....	....	....	....	....	....	....	....	....
Glycymeris sp.	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....
Pinna sp.	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....
Perna sp.	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....
Ostrea haitensis Sowerby	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ostrea sp. cf. O. folium Linnaeus	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ostrea sp.	×	×	×	×	....	....	....	....	....	....	....	×	×	....	×	....	....	×	....
Pecten (Pecten) soror Gabb	....	....	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Chlamys (Chlamys) sp	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Chlamys (Aequipecten) sp. a cf. unnamed Cercado sp	×	×	....	....	....	....	....	....	....	?	....	×	....	....	....	....	....	....	....
Chlamys (Aequipecten) sp. b	×	....	....	?	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Chlamys (Aequipecten) sp. c cf. C. (A.) thompsoni (Maury)	×	....	×	?	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....
Chlamys (Aequipecten) sp. d cf. unnamed Cercado sp	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Amusium (Amusium) sp	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Plicatula sp.	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

Anomia sp. cf. A. indecisa Dall	×	×	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Mytilopsis sp.	×	×	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Crassinella microdelta Pilsbry and Johnson	×	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Crassinella n. sp. a	×	×	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Crassinella sp. cf. C. bowdenensis (Dall)	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Cyrena (Pseudocyrena) n. sp.	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Chama sp. cf. C. involuta Guppy	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Codakia ? sp.	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Lucina sp. cf. L. chrysostoma Philippi	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Phacoides (Parvilucina) n. sp. a cf. P. (P.) yaquensis Gabb, also from Baitoa formation	×	×	....	×	....	....	....	....	....	....	....	×	....	....	×	....	....	....	....	....
Phacoides (Parvilucina) n. sp. b.	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Divaricella sp. cf. D. prevaricata Guppy	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Diplodonta sp.	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Montacuta sp.	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Sportella ? sp.	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Alveinus n. sp. cf. A. rotundatus Dall, also from Baitoa formation	×	×	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Alveinus sp.	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Cardium (Cardium) n. sp.	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....	....
Cardium (Trachycardium) sp. a	×	×	....	....	....	....	....	....	....	....	....	?	....	....	?	....	....	....	....	....
Cardium (Trachycardium) sp. b.	....	....	....	×	....	....	....	....	....	?	?	....	....	....	....	....	....	....	....	....
Cardium (Trachycardium) sp. c.	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....	....
Cardium (Trigoniocardia) sp. cf. C. (T.) aminense Dall	×	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Protocardia ? sp.	....	....	....	×	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....	....
Dosinia sp. cf. D. chipolana Dall.	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Dosinia ? sp.	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....	....
Clementia ? sp.	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Transennella sp.	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Macrocallista ? sp.	....	....	....	×	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....	....
Callocardia ? sp.	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....	....
Pitar ? (Lamelliconcha ?) sp.	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Pitar (Hyphantosoma) sp. cf. P. (H.) carbaseus (Guppy)	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Cytherea sp. cf. C. tarquinia (Dall)	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....	....
Antigona (Ventricola) sp. cf. A. (V.) blandiana (Guppy)	×	×	....	....	....	....	?	....	....	....	....	....	....	....	....	....	....	....	....	....
Chione sp. cf. C. woodwardi (Guppy)	×	....	....	....	....	....	....	....	....	?	....	....	....	....	....	....	....	....	....	....

Miocene fossils from Thomonde formation in Central Plain—Continued.

Species.	Upper zone.													Middle zone.		Lower zone.			
	Hinche.			Las Cahobas.										Hinche.		Las Cahobas.	Hinche.	Marmelade.	Las Cahobas.
	9945	9946	9947	9782	9779	9791	9780	9781	9785	9929	9778	9907	9908	9926	9948	9935	9719	9939	9904
Chiona sp. cf. C. socia Pilsbry and Johnson	....	....	....	....	....	....	....	....	....	....	....	×	×	....	×	....	....	....	....
Anomalocardia ? sp.	×	×	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Tellina sp. a	×	×	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Tellina sp. b	....	×	....	?	....	....	....	....	....	....	....	?	?	....	....	....	....	....	....
Tellina sp. c	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Tellina sp. indet	....	....	....	....	....	....	×	....	....	×	....	....	....	....	×	....	×	....	....
Macoma sp.	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....
Macoma ? sp. indet	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	×	....	....	....
Macoma (Psammacoma) sp. cf. M. (P.) olivella Dall	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Metis ? sp.	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Strigilla sp. cf. S. pisiformis (Linnaeus)	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Tagelus sp.	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Sphenia sp.	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ervilia sp.	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....
Corbula sp. a cf. C. cercadica Maury	×	×	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Corbula sp. b cf. C. sericea Dall	×	×	....	×	....	....	....	....	....	×	....	....	....	....	....	....	×	....	....
Corbula sp. c cf. C. knoxiana fossilis Pilsbry	×	×	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Corbula sp. d cf. C. dominicensis Gabb	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Corbula (Aloidis) vieta Guppy	....	×	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Corbula (Bothrocorbula) viminea Guppy	×	....	....	×	....	×	....	....	....	....	....	×	×	....	×	....	....	....	....
Rocellaria sp. cf. R. rotunda (Dall)	....	×	....	....	....	....	....	....	....	....	....	×	×	....	....	....	....	....	....
Decapod Crustacea:																			
Portunus (Portunus) haitensis Rathbun	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....
Panopeus sp. indet	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Panopeus ? sp.	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Parthenope ? sp.	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....

Fossils, Maïssade tongue.—Mollusks and decapod Crustacea are the most abundant fossils obtained from the Maïssade tongue of the Thomonde formation. No corals were found in the Maïssade tongue, as the deposits were laid down near the mouths of streams that flowed across coastal-plain swamps. Some of the characteristic mollusks are shown on Plate XVI.

The collections of mollusks are divided into three lists to show that some of them contain a marine fauna, others a mixed marine and brackish fauna, and others a brackish fauna. The list on pages 194-195 shows that the marine fauna is essentially the same as the fauna in the middle part of the Thomonde formation in the southeastern part of the plain, 44 per cent of the species being identical. The most striking identical species are several species of Tectibranchs and Pleurotomids, several small species of *Marginella, Melongena orthocantha* Pilsbry and Johnson (Pl. XVI, fig. 5), *Phos costatus* Gabb (Pl. XV, figs. 4, 5), *Turritella sulcigyrata* Pilsbry and Brown, and *Scapharca chiriquiensis* Gabb (Pl. XVI, figs. 6-8). Some of the species in the Maïssade tongue are known also in the upper part of the Thomonde formation in the southeastern part of the plain, but *Xancus rex* Pilsbry and Johnson, *Phos semicostatus* Gabb, and *Orthaulax aguadillensis* Maury are not found in the Maïssade tongue. The absence of some of these species and of the Cones may be due to environmental conditions, but the evidence seems to indicate that the lower and middle parts of the Maïssade tongue, which contain the marine fauna, are the equivalent of the middle part of the Thomonde formation.

The collections containing a mixed marine and brackish fauna are listed on page 196. The dwarf race of *Phos costatus* Gabb and species of *Hydrobia* and *Tryonia* indicate a brackish element. The same dwarf race of *Phos costatus* was found in the marine beds, but the collection from station 9717, the largest marine faunule, includes typical specimens of this species.

The collections containing a brackish fauna are listed on page 197.

Potamides tippenhaueri Woodring and Mansfield (see p. 611 and Pl. XVI, figs. 3, 4), *Melongena orthocantha* Pilsbry and Johnson (Pl. XVI, fig. 5), *Scapharca chiriquiensis* (Gabb) (Pl. XVI, figs. 6-8), and subspecies *websteri* (Pilsbry) (Pl. XVI, figs. 9-11), and *Ostrea* sp., are the most abundant mollusks in the Maïssade tongue. Whole beds consist of *Scapharca chiriquiensis*, and others are made up of oyster shells. *Potamides roumaini* Pilsbry (Pl. XVI, figs. 1, 2) is remarkably abundant at station 9710.

Stations in Central Plain, Maïssade tongue (Miocene).

9710 (W 246 F). Arrondissement of Hinche, right bank of Rivière Frio about 100 meters above crossing of road from Maïssade to Hinche. W. P. Woodring, collector. February 1, 1921.

9711 to 9715. Arrondissement of Hinche, right bank of Rivière Fond Gras, about a kilometer in air line above junction with Rivière Canot. (See p. 172 for

PLATE XVI.

SOME CHARACTERISTIC MOLLUSKS OF THE MAÏSSADE TONGUE AND OF THE ARTIBONITE GROUP.

FIGURES 1, 2. *Potamides roumaini* Pilsbry. Maïssade tongue, U. S. G. S. station 9710. U. S. N. M. catalogue No. 350580.

Fig. 1. Adult specimen, × 1.

Fig. 2. Young specimen, × 2, showing sculpture of early whorls.

FIGURES 3, 4. *Potamides tippenhaueri* Woodring and Mansfield (p. 611). Maïssade tongue, U. S. G. S. station 9725.

Fig. 3. Type, × 1. U. S. N. M. catalogue No. 350581.

Fig. 4. Young specimen, × 2, showing sculpture of early whorls. U. S. N. M. catalogue No. 350582.

FIGURE 5. *Melongena orthocantha* Pilsbry and Johnson, × 1. Maïssade tongue, U. S. G. S. station 9732. U. S. N. M. catalogue No. 350583.

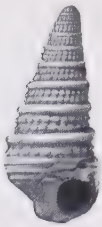
FIGURES 6, 7, 8. *Scapharca chiriquiensis* (Gabb). Three views of same specimen, × 1. Thomonde formation U. S. G. S. station 9908. U. S. N. M. catalogue No. 350584.

FIGURES 9, 10, 11. *Scapharca chiriquiensis websteri* (Pilsbry). Three views of same specimen, × 1. Las Cahobas formation, U. S. G. S. station 9930. U. S. N. M. catalogue No. 350585.

1

× 2

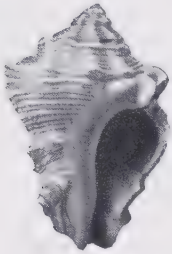
2



3

× 2

4



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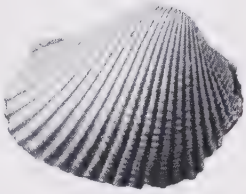
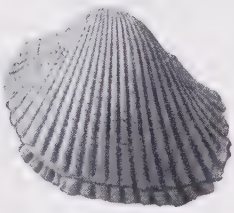


9

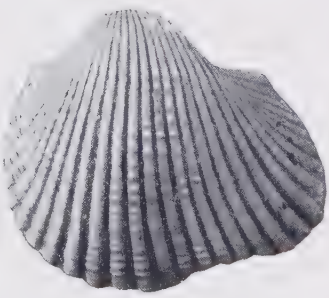
7

10



11

6



8

CHARACTERISTIC MOLLUSKS OF THE MAÏSSADE TONGUE AND OF THE ARTIBONITE GROUP.

Miocene marine fossils from Central Plain (Maïssade tongue).

Species.	Hinche.				Marmelade.	
	9717	9713	9714	9715	9722	9726
Mollusca:						
Gastropoda:						
Actaeon sp. cf. A. riomaensis Maury	....	....	....	....	×	....
Acteocina n. sp. a cf. A. subbullata Pilsbry and Johnson.	?	....	....	....	....	....
Acteocina n. sp. b, also from Cercada formation	....	....	....	....	×	....
Cylichnella n. sp. a cf. C. trictum-tritonis Maury	×	....	....	....	....	....
Ringicula n. sp. b cf. R. dominicana Maury	....	....	....	×	×	....
Bullaria sp. indet	....	....	....	×	....	....
Turris (Pleuroliria) sp. a cf. new species from Cercado formation	?	....	....	....	....	....
"Drillia" sp. cf. n. sp. b	×	....	....	....	....	....
"Drillia" sp. b cf. new species from Cercado formation	×	....	?	....	....	....
"Drillia" sp. c cf. new species from Cercado formation	....	....	×	....	....	....
"Mangilia" sp. f	....	....	?	×	....	....
"Mangilia" sp. g	×	....	....	....	....	....
"Mangilia" sp. indet	....	....	....	....	×	....
Olivella (Lamprodroma) sp. cf. O limonensis Olsson	....	....	....	×	....	....
Marginella nugax Pilsbry and Johnson	×	....	....	....	....	....
Marginella n. sp. a cf. M. maoensis Maury	×	....	....	....	....	....
Marginella n. sp. c cf. M. oryzoides Gardner (Mss.)	?	....	....	....	....	....
Marginella sp. b cf. M. latissima Dall	....	....	....	×	....	×
Marginella sp. c	....	....	×	....	....	....
Marginella (Gibberula) sp. b cf. M. chondra Gardner (Mss.)	×	....	....	....	....	....
Marginella (Gibberula) sp	....	....	....	....	....	×
Mitra (Cancilla) n. sp. a cf. M. (C.) henekeni Sowerby	....	×	×	×	×	×
Mitra (Fusimitra) n. sp. c cf. M. (F.) mangilopsis Gardner (Mss.)	×	....	....	....	....	....
Mitra (Fusimitra) sp	×	....	....	....	....	....
Fusinus sp.	×	....	....	....	....	....
Melongena orthocantha Pilsbry and Johnson	....	....	×	....	....	×
Phos costatus Gabb	×	....	....	....	....	....
Phos costatus Gabb (dwarf race)	....	....	×	....	×	×
Strombina n. sp. b, cf. S. caribaea Gabb	×	×	×	×	×	....
Murex sp. a cf. M. messorius Sowerby	...	×	....	×	×	....
Cerithium (Vulgocerithium) sp. cf. C. (V.) dominicense Gabb	....	....	×	....	....	....
Cerithium ? sp	....	....	....	....	×	×
Clava alajuela Olsson	....	....	×	×	....	....
Potamides tippenhaueri Woodring and Mansfield	....	....	....	....	....	×
Cerithidea sp. a	×	....	....	....	....	....
Bittium sp. b	....	....	....	....	×	....
Bittium sp.	×	....	....	....	....	×
Cerithiopsis sp. d	×	....	....	....	....	....
Triphora sp. a	×	....	....	....	....	....
Vermicularia sp. cf. V. spirata (Philippi)	×	....	....	....	....	....
Turritella calostemma Pilsbry and Brown	....	×	....	×	....	....
Turritella sulcigyrata Pilsbry and Brown	×	×	....	....	....	....
Caecum sp. cf. C. anellifer Pilsbry and Johnson	×	....	....	....	....	....
Meioceras sp. cf. M. constrictum (Gabb)	....	....	....	....	....	×

Miocene marine fossils from Central Plain (Maïssade tongue)—Continued.

Species.	Hinche.				Marmelade.	
	9717	9713	9714	9715	9722	9726
Mollusca—(Cont'd):						
Gastropoda—(Cont'd):						
Meioceras n. sp. a	×	....	....	....	....	....
Fossarus (Isapis) sp. b	....	....	....	....	×	....
Hydrobia sp.	....	....	....	×	....	....
Tryonia sp. d	....	....	×	....	....	....
Crepidula sp.	....	....	....	....	×	....
Epitonium sp.	....	....	....	....	×	....
Melanella sp	....	×	....	....	....	....
Turbonilla sp. e	×	....	×	....	....	....
Turbonilla sp. g	×	....	....	....	....	....
Turbonilla sp. h	....	....	....	×	×	?
Odostomia sp. c	....	....	×	....	....	....
Odostomia sp. d	....	....	×	....	....	....
Odostomia sp. e	....	....	....	....	×	....
Odostomia sp. f	....	....	....	....	×	....
Neritina (Smaragdia) viridimaris Maury	×	....	....	....	....	....
Neritina (Puperita) figulopicta Maury	....	....	×	....	....	....
Liotia sp. a	×	....	....	....	....	....
Circulus sp.	....	....	....	....	×	....
Vitrinella sp.	....	....	....	×	....	....
Teinostoma depressum (Gabb)	?	....	×	×	....	....
Discopsis sp.	×	....	....	....	....	....
Scaphopoda:						
Cadulus sp. b cf. C. colobus Pilsbry and Sharp	....	....	....	....	×	....
Pelecypoda:						
Nucula tenuisculpta Gabb	×	....	....	....	×	×
Leda n. sp. a cf. L. extricata Pilsbry and Johnson	....	....	....	....	×	....
Leda n. sp. b	?	....	×	....	....	....
Scapharca chiriquiensis (Gabb)	....	×	×	×	....	×
Scapharca sp.	....	×	....	....	×	....
Ostrea sp.	×	×	....	×	×	×
Amusium (Pseudamusium) sp. cf. A. (P.) guppyi (Dall)	×	....	....	....	....	. ..
Anomia sp.	....	....	....	....	×	....
Modiolus (Brachydontes) sp.	....	....	×	....	×	....
Mytilopsis sp.	....	....	....	....	....	×
Crassinella n. sp. a	....	....	?	....	....	....
Cyrena sp.	?	....	×	....	....	....
Phacoides (Parvilucina) n. sp. b	×	....	×	....	×	×
Chione sp. cf. C. socia Pilsbry and Johnson	....	×	×	....	....	....
Ervilia sp.	×	...	....	....	....	....
Tellina sp.	×	×	×	....	....	×
Macoma ? sp	....	....	×	....	....	....
Corbula sp. c cf. C. knoxiana fossilis Pilsbry	×	....	×	....	....	....
Rocellaria sp. cf. R. rotunda (Dall)	....	....	×	....	....	....
Decapod Crustacea:						
Portunus (Portunus) haitensis Rathbun	×	....	....	....	×	....

Miocene marine and brackish-water fossils from Central Plain (Maïssade tongue).

Species.	Hinche.		Marmelade.							
	9711	9716	9723	9724	9725	9727	9728	9729	9732	9733
Mollusca:										
Gastropoda:										
Ringicula n. sp. b. cf. R. dominicana Maury	....	....	....	....	....	....	....	....	×	....
Ringicula sp.	....	....	....	....	....	....	....	....	×	....
Olivella (Lamprodroma) sp. a	×	....	....	....	....	....	....	....	....	....
Melongena consors (Sowerby)	×	×	....	....	....	....	?	....	....	×
Melongena orthocantha Pilsbry and Johnson	....	×	×	....	×	×	×	....	×	....
Phos costatus Gabb (dwarf race)	....	×	....	....	....	....	....	....	....	....
Atilia sp.	....	....	×	....	....	....	....	....	....	....
Strombina n. sp. b cf. S. caribaea Gabb	....	×	....	....	....	....	....	....	....	....
Strombina sp. b	....	....	....	....	....	....	....	....	×	....
Murex sp. a cf. M. messorius Sowerby	....	....	×	....	....	....	....	....	....	....
Potamides tippenhaueri Woodring and Mansfield	×	....	....	....	×	×	×	....	×	×
Bittium sp. b	....	....	....	×	....	....	....	....	....	....
Bittium sp. d	....	....	....	....	....	....	....	....	×	....
Bittium sp. e	....	....	....	....	....	....	....	....	×	....
Bittium sp. f	×	×	....	....	....	....	....	....	....	....
Bittium sp.	....	....	....	....	....	....	....	....	....	×
Hydrobia sp.	×	×	....	....	....	....	....	....	....	....
Tryonia sp. d	×	....	....	....	....	....	....	....	×	....
Crucibulum sp.	....	....	....	....	....	....	....	×	....	....
Turbonilla sp.	....	....	....	....	....	....	×	....	....	....
Neritina (Puperita) figulopicta Maury	×	....	×	....	....	×	....	....	....	×
Pelecypoda:										
Leda n. sp. b	....	×	....	....	....	....	....	....	....	....
Scapharca chiriquiensis (Gabb)	×	×	×	×	....	....	×	×	×	×
Scapharca chiriquiensis websteri (Pilsbry)	....	....	×	....	×	....	....	....	....	....
Ostrea sp.	....	×	×	×	....	....	....	....	....	....
Mytilopsis sp.	×	....	×	....	....	×	....	×	×	....
Phacoides (Parvilucina) n. sp. b	×	....	....	....	....	....	....	....	×	....
Chione sp. cf. C socia Pilsbry and Johnson	....	×	....	....	×	....	....	....	....	....
Tellina sp.	×	....	....	....	....	....	....	....	....	....
Corbula sp. c cf. C knoxiana fossils Pilsbry	....	×	....	....	....	....	....	....	....	....

section.) W. P. Woodring, collector. February 2, 1921. The beds in the section that yielded the fossils are 9711 (W 248 F), bed 14; 9712 (W 249 F), bed 12; 9713 (W 250 F), bed 6; 9714 (W 251 F), bed 4; 9715 (W 252 F), bed 3.

9716 (W 253 F). Arrondissement of Hinche, right bank of Rivière Fond Gras, about half a kilometer below junction with Rivière Fond Bleu. W. P. Woodring, collector. February 2, 1921.

9717 (W 254 F). Arrondissement of Hinche, right bank of Rivière Fond Bleu, about half a kilometer above junction with Rivière Fond Gras. W. P. Woodring, collector. February 2, 1921.

9718 (W 255 F). Arrondissement of Hinche, right bank of Rivière Fond Bleu, about 2.5 kilometers above junction with Rivière Fond Gras. W. P. Woodring, collector. February 2, 1921.

9722 to 9733. Arrondissement of Marmelade, first high bluff on right bank of Rivière Blanche below gorge formed by conglomerates in middle part of Thomonde formation. (See pp. 170-172 for section.) W. P. Woodring, collector. February 5, 1921. The beds in the section that yielded the fossils are 9722 (W 262a F), bed 47; 9723 (W 262b F), bed 46; 9724 (W 262c F), bed 44; 9725 (W 262d F), bed 43; 9726 (W 262e F), bed 36; 9727 (W 262f F), bed 34; 9728 (W 262g F), bed 32; 9729 (W 262h F), bed 29; 9730 (W 262i F), bed 24; 9731 (W 262j F), bed 21; 9732 (W 262k F), bed 6; 9733 (W 262l F), bed 2.

Miocene brackish-water fossils from Central Plain (Maïssade tongue).

Species.	Hinche.			Marmelade.	
	9710	9718	9712	9730	9731
Mollusca:					
Gastropoda:					
Planorbis sp.	....	....	....	×	....
Bullaria sp.	×	....	....	....	....
Potamides roumaini Pilsbry	×	....	....	....	....
Potamides tippenhaueri Woodring and Mansfield	....	....	....	....	×
Alabina sp.	....	×	....	....	....
Hemisinus truncatus (Gabb)	....	×	×	?	×
Hemisinus sp.	....	×	....	....	....
Hydrobia sp.	....	....	....	×	....
Tryonia sp. e	×	....	....	....	....
Pelecypoda:					
Scapharca chiriquiensis websteri (Pilsbry)	?	....	×	....	....
Mytilopsis sp.	×	....	....	....	....

LAS CAHOBAS FORMATION.

Jones[1] gave the name "Las Cahobas beds," derived from that of the town of Las Cahobas, to the rocks that overlie the Thomonde formation. The type locality is north of Las Cahobas. The Las Cahobas formation is the youngest Miocene formation in the Central Plain and the most extensive surface formation in its southeastern part, but at many places in the interior it is concealed by younger stream deposits. It conformably over-

[1] Jones, W. F., op. cit., p. 737, 1918.

lies the Thomonde formation but was laid down along a retreating shore line. Its estimated maximum thickness is 700 meters.

Along the west and south edges of the plain the Las Cahobas formation is strikingly different in lithology from the underlying Thomonde formation, as it consists almost entirely of coarse detrital sediments, principally conglomerates and coarse cross-bedded sandstones. These deposits are largely nonmarine and apparently represent delta and flood-plain deposits that extended far seaward beyond the shore line of Thomonde time. As these rocks are harder than the Thomonde rocks they form ridges with steep mountain-facing cuestas. Such a ridge formed by the basal rocks of the Las Cahobas formation is a striking feature along the south edge of the plain. (See Pl. XIV, *B*.)

North and northeast of Las Cahobas there are two coralliferous limestones at and near the base of the formation. The lower limestone, which is considered the base of the formation, crops out in a low ridge about half a kilometer north of Las Cahobas. It is yellowish and rather soft. Heads of *Orbicella* and branches of *Stylophora* and *Pocillopora* weather out of the rock and lie on the ground. The corals listed on page 203 (station 9906) were collected at this locality. This limestone is exposed on the main trail leading northeastward from Las Cahobas, about a quarter of a kilometer from the town, where it overlies thin-bedded sandstone and sandy siltstone at the top of the Thomonde formation. About 50 meters farther northeast the trail turns eastward and passes over a coralliferous limestone about 20 meters higher stratigraphically. This limestone is hard and grayish but weathers yellowish. It contains many corals, especially *Stylophora, Pocillopora, Orbicella,* and *Cyathomorpha.* (See list, p. 203; stations 9909 and 9773.) This limestone is overlain by shaly beds and poorly exposed coarse sandstone and conglomerate consisting of small pebbles. Farther to the northeast a conspicuous bed about 40 centimeters thick, consisting of the large massive valves of *Ostrea cahobasensis,* crops out west of the trail (station 9910). At the place where the Belladère trail branches off from the Thomonde trail a bed of dark-gray siltstone contains the mollusks listed on page 204 (station 9772). The overlying beds consist of soft rusty-brown sandstone, white poorly consolidated cross-bedded sandstone, and conglomerate.

The higher of the two coralliferous limestones forms the crest of the high ridge north of Las Cahobas. The ruins of Fort Anglais, built by the British during their occupation, stand on this ridge. The walls of the fort are constructed of blocks of this limestone. The corals listed on page 203 (station 9905) were collected loose along the south slope of the ridge, having weathered out and rolled down the slope.

The lower part of the Las Cahobas formation is exposed at many other localities near Las Cahobas. Most of the beds above the coralliferous limestones are conglomerates or coarse sandstones. The conglomerates contain pebbles of limestone, argillite, and various igneous rocks, all derived

from the present region of the Massif du Nord. *Ostrea bolus* was collected from coarse poorly consolidated sandstone exposed along the trail from Las Cahobas northwestward to Rivière Artibonite (station 9988).

The trail from Las Cahobas to Belladère approximately follows the strike of the rocks for the greater part of the distance. Conglomerate and sandstone crop out in many gullies and ravines. The beds at the base of the Las Cahobas formation form a " rim rock " curving around the northwestward-plunging crest of the Belladère anticline. Large valves of *Ostrea cahobasensis* were collected from a bed near the base of the formation on the south limb, where the dip is 55°. The coralliferous limestones at the base of the formation are not so prominent here as near Las Cahobas.

Along the trail from Las Cahobas to Thomonde there are many exposures of beds higher in the Las Cahobas formation. Like the lower beds they consist principally of conglomerate and sandstone, but they contain no fossils. Beds at the base of the formation form the " rim rock " on the southeastward-plunging crest of the Chamouscadille anticline, which is visible from the trail. Oysters and other marine fossils were collected from beds in the lower half of the formation. (See lists, pp. 203-204; stations 9774, 9775, 9776, and 9916.)

Successively lower beds appear at the surface on the ascent of the high ridge overlooking Thomonde. This ridge is part of the " rim rock " formed by the basal beds of the formation that curve around the southeastward-plunging crest of the Thomonde anticline. Westward and eastward from the trail long, gentle dip slopes on the south limb of the anticline are visible. They are formed by beds of conglomerate. The crest of the ridge consists of conglomerate. Above and below the conglomerate lies a coralliferous limestone in the same stratigraphic position as the limestones at the base of the formation at Las Cahobas. Here the septa of the corals are dissolved, and the only specimens obtained are casts of *Stylophora* from the upper limestone (station 9777). Below the lower limestone lies a conglomerate containing small pebbles and below the conglomerate lies sandy siltstone that contains Thomonde fossils (station 9778).

The lower part of the Las Cahobas formation is well exposed on the north limb of the Thomonde anticline, where it forms a " rim rock " that is a continuation of the ridge on the south limb described above. On the trail from Thomonde to Hinche the beds dip from 70° to 80°, or even 90°. The following generalized section was measured along this trail:

Generalized section of lower part of Las Cahobas formation and upper part of Thomonde formation on trail from Thomonde to Hinche.

Las Cahobas formation:	Est. thickness in meters.
29. Coarse sandstone	1
28. Oyster bed	.5
27. Conglomerate	1
26. Oyster bed	.5
25. Sandy siltstone	2

Las Cahobas formation—Continued.	Est. thickness in meters.
24. Oyster bed	.5
23. Conglomerate	1
22. Oyster bed	.5
21. Sandy siltstone	1
20. Oyster bed	.2
19. Sandstone	1
18. Conglomerate	.5
17. Siltstone, marine fossils; station 9927	5
16. Conglomerate	3
15. Coralliferous limestone	1.2
14. Conglomerate	3
13. Coralliferous limestone; station 9928	1.6
12. Conglomerate	5
11. Sandstone	5
10. Conglomerate	3
9. Sandy siltstone	2
8. Conglomerate	1
7. Sandy siltstone	2
6. Conglomerate	3
Thomonde formation:	
5. Siltstone; numerous casts of mollusks; station 9929	10
4. Conglomerate	.5
3. Sandy siltstone	2
2. Conglomerate	.5
1. Siltstone	50
	107.5

In this section the coralliferous limestones seem to lie higher above the highest Thomonde fauna than elsewhere. The collection from station 9927 (bed 17 of preceding section) contains fragments of dicotyledonous leaves, probably representing the genus *Ficus,* in addition to marine mollusks.

On the trail from Thomonde to Thomassique a yellowish coralliferous limestone lies above beds of heavy conglomerate and coarse sandstone at the base of the formation. The corals listed on page 203 (station 9783) were collected at this locality. Farther northeast on this trail the beds flatten abruptly in the trough of the Central Plain syncline. They consist of alternating beds of conglomerate, sandstone, and siltstone. They are irregularly bedded and seem to be flood-plain and delta deposits. The siltstones have a reddish or greenish color, which is in striking contrast to the bluish color of the marine siltstones. These are the highest Las Cahobas beds examined.

Similar beds crop out in ravines and gullies along the trail from Thomonde to Hinche, north of the ridge described on page 198, but on the upland they are concealed by younger stream deposits. As these higher Las Cahobas beds are stream deposits they can hardly be distinguished from the younger stream deposits in the regions where they lie flat.

At Hinche, on the right bank of Rivière Guayamouc, a high bluff exposes in ascending order rusty-brown sandstone, siltstone, and a bed of sandy clay about 60 centimeters thick, which contains fragments of leaves and thin streaks of lignite. These beds seem to lie horizontal, but the river flows along the strike and they probably dip gently southeastward. Sandy clay containing a few small pebbles overlain by buff clay is exposed in bluffs on the left bank of Rivière Guayamouc opposite Hinche, about 150 meters back from the river. Ponderous valves of *Ostrea cahobasensis* were collected at the foot of the bluff. These beds dip 3° to 4° SW.

On the northeast side of the plain the Las Cahobas formation is lithologically indistinguishable from the Thomonde formation, as both consist principally of coarse detrital sediments and are included in the thick wedge of delta and flood-plain deposits that tapers southwestward away from the old landmass. Thin wedges of sandstone and siltstone near the base of the formation carry a marine fauna (see pp. 202, 205; stations 9930 and 9931), showing that in early Las Cahobas time the sea at times extended northeastward over the area where delta and flood plain deposits were usually being laid down. These marine deposits probably are the littoral equivalent of the coralliferous limestones, which are not found on this side of the plain. The boundary between the Thomonde and Las Cahobas formations on this side of the plain is drawn immediately above the highest beds carrying a Thomonde fauna.

Fossils.—The Las Cahobas formation includes deposits of different origin, and the collections of fossils obtained from them are correspondingly diverse. The coralliferous limestones near the base of the formation on the west side of the plain contain an extensive coral fauna of reef facies and apparently represent a horizon from which a reef fauna has not been collected in the Dominican Republic. For this reason the corals of the Las Cahobas formation have a peculiar aspect, some of the species heretofore being known only from older beds and others only from younger beds. *Orbicella imperatoris* Vaughan was formerly thought to be an upper Oligocene species, and the genus *Cyathomorpha* was formerly thought to be extinct before Miocene time. In the northern part of the Dominican Republic *Stylophora monticulosa* Vaughan (MS.) and *Pocillopora crassoramosa* Duncan are confined to the Gurabo formation and Mao Adentro limestone. Both of these species are very abundant in the Las Cahobas formation.

Oysters are the most abundant mollusks on the west side of the plain. Whole beds are composed of the large, heavy valves of *Ostrea cahobasensis* Pilsbry and Brown. Other beds contain the smaller species *O. bolus* Pilsbry and Johnson. Both of these species are confined to the Las Cahobas formation. The large plicate oyster *O. haitensis* Sowerby was found in both the Thomonde and Las Cahobas formations. Some beds contain large numbers of *Scapharca chiriquiensis* Gabb (Pl. XVI, figs. 6-8), which also is a common Thomonde fossil, especially in the Maïssade tongue. This

species, though found in strictly marine beds, seems to have been adapted to living in brackish water. Beds near the base of the formation contain a meager marine fauna.

The mollusks listed under stations 9930 and 9931 were obtained from beds slightly higher than beds carrying *Orthaulax aguadillensis* and other mollusks typical of the upper faunal zone of the Thomonde formation. Many of the species, such as *Conus* n. sp., the Marginellas, *Melongena orthocantha* Pilsbry and Johnson (Pl. XVI, fig. 5), and *Scapharca chiriquiensis websteri* (Pilsbry) (Pl. XVI, figs. 9-11), are common Thomonde species, and if the stratigraphic position of these beds were not known they probably would be included in the Thomonde formation. They are supposed to be the littoral equivalent of the coralliferous limestones at the base of the Las Cahobas formation on the west side of the plain. The inclusion of these beds in the Las Cahobas formation weakens the faunal evidence for considering the Maïssade tongue a part of the Thomonde formation, as the mollusks from these Las Cahobas beds are very similar to those in the marine beds of the Maïssade tongue.

The Las Cahobas formation is the equivalent of the Cercado formation of the Dominican Republic, although the faunas of the two formations are not at all comparable because of dissimilar environmental conditions. The corals indicate that the Las Cahobas formation is the equivalent of an unknown part of the Yaque group of the valley of Rio Yaque del Sur, Dominican Republic. Because of its correlation with the Cercado formation the Las Cahobas formation seems to be of upper Burdigalian age.

Stations in Central Plain, Las Cahobas formation (Miocene).

West side of plain.

9909 (W 193 F). Arrondissement of Las Cahobas, trail from Las Cahobas to Thomonde and Belladère, about 0.25 kilometer northeast of Las Cahobas. W. P. Woodring, collector. January 11, 1921.

9773 (W 314 F). Arrondissement of Las Cahobas, same locality as 9909. T. W. Vaughan and W. P. Woodring, collectors. March 1, 1921.

9906 (W 188 F). Arrondissement of Las Cahobas, low ridge about 0.6 kilometer north of Las Cahobas, at an altitude of 260 meters above sea level. W. P. Woodring, collector. January 9, 1921.

9905 (W 187 F). Arrondissement of Las Cahobas, float along south slope of high ridge about a kilometer north of Las Cahobas, coralliferous limestone in place at crest of ridge. W. P. Woodring, collector. January 9, 1921.

9910 (W 194 F). Arrondissement of Las Cahobas, on trail from Las Cahobas to Thomonde and Belladère, about a kilometer northeast of Las Cahobas. W. P. Woodring, collector. January 11, 1921.

9772 (W 195 F). Arrondissement of Las Cahobas, on trail from Las Cahobas to Thomonde, at place where Belladère trail branches off. W. P. Woodring, collector. January 11, 1921.

9988 (W 189 F). Arrondissement of Las Cahobas, on trail leading north-northwestward from Las Cahobas to Rivière l'Ayaye, about 5 kilometers from Las Cahobas. W. P. Woodring, collector. January 10, 1921.

9911 (W 198 F). Arrondissement of Las Cahobas, on trail from Las Cahobas to Belladère, south limb of Belladère anticline, about 4 kilometers west of Belladère. W. P. Woodring, collector. January 12, 1921.

9774 (W 204 F). Arrondissement of Las Cahobas, on trail from Las Cahobas to Thomonde, about 1.5 kilometers north of cemetery at Savane Chamouscadille. W. P. Woodring, collector. January 15, 1921.

9775 (205a F). Arrondissement of Las Cahobas, on trail from Las Cahobas to Thomonde, about 2 kilometers north of cemetery at Savane Chamouscadille. W. P. Woodring, collector. January 15, 1921.

9776 (W 205b F). Arrondissement of Las Cahobas, same locality as 9775 but from underlying bed. W. P. Woodring, collector. January 15, 1921.

9777 (W 206 F). Arrondissement of Las Cahobas, south limb of Thomonde anticline, on trail from Las Cahobas to Thomonde, crest of ridge formed by base of Las Cahobas formation, about 3 kilometers southeast of Thomonde, at an altitude of 395 meters above sea level. W. P. Woodring, collector. January 15, 1921.

9916 (W 205c F). Arrondissement of Las Cahobas, same locality as 9776 but from underlying bed. W. P. Woodring, collector. January 15, 1921.

9927 (W 233 F). Arrondissement of Las Cahobas, north limb of Thomonde anticline, on trail from Thomonde to Hinche, north slope of ridge formed by base of Las Cahobas formation, about 4.5 kilometers north-northwest of Thomonde, at an altitude of 350 meters above sea level. W. P. Woodring, collector. January 26, 1921.

9928 (W 234 F). Arrondissement of Las Cahobas, north limb of Thomonde anticline, on crest of ridge formed by base of Las Cahobas formation, 0.5 kilometer west of trail from Thomonde to Hinche. W. P. Woodring, collector. January 26, 1921.

9783 (W 212 F). Arrondissement of Las Cahobas, north limb of Thomonde anticline, on trail from Thomonde to Thomassique, north slope of ridge formed by base of Las Cahobas formation, about 2.8 kilometers east-northeast of Thomonde. W. P. Woodring, collector. January 16, 1921.

9944 (W 318 F). Arrondissement of Hinche, float at foot of bluffs on left bank of Rivière Guayamouc opposite Hinche, about 150 meters northeast of upper crossing. W. P. Woodring, collector. March 12, 1921.

East side of plain.

9930 (W 236 F). Arrondissement of Las Cahobas, right bank of Ravine Boucan Toureau, about 0.5 kilometer southwest of Thomassique. W. P. Woodring, collector. January 27, 1921.

9931 (W 237 F). Arrondissement of Las Cahobas, right bank of Rivière Honde about 2 kilometers above crossing of trail from Thomassique to Thomonde. W. P. Woodring, collector. January 28, 1921.

Miocene fossils from Central Plain, Las Cahobas formation.

West side of plain.

Species.	Las Cahobas.																Hinche.
	9909	9773	9906	9905	9910	9772	9988	9911	9774	9775	9776	9777	9916	9927	9928	9783	9944
Foraminifera:																	
Sorites sp. cf. americana (Cushman)	....	....	....	....	....	....	....	....	....	....	....	....	×	×	....	....	....
Corals:																	
Stylophora monticulosa Vaughan (MS.)	×	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Stylophora n. sp., also from station 8610, Yaque group, Dominican Republic	×	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Stylophora sp.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Pocillopora cressoramosa Duncan	×	×	×	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Pocillopora sp.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Dichocoenia stokesi Milne-Edwards and Haime	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	×	....
Antillia dubia (Duncan)	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Antillia sp. cf. A. walli Duncan	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Orbicella imperatoris Vaughan	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Orbicella sp. cf. O. imperatoris Vaughan	×	....	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....
Orbicella sp. cf. O. annularis (Ellis and Solander), smaller secondary septa	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Orbicella cavernosa (Linnaeus) var	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Solenastrea bournoni Milne-Edwards and Haime	....	....	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....
Solenastrea hyades (Dana)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....
Mycetophyllia sp. a	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Mycetophyllia sp. b	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Agaricia sp., also from Gurabo formation and Mao Adentro limestone	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Cyathomorpha n. sp	×	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....
Genus ? fungid coral, cf. Cyathomorpha, but reproduction by fission	....	....	....	×	....	....	....	....	....	....	....	....	....	....	×	....	....
Psammocora n. sp. c	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Psammocora n. sp. d	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Porites sp. aff. P. furcata Lamarck	×	....	×	....	....	....	....	....	....	....	....	....	....	....	....	×	....
Goniopora jacobiana Vaughan	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Goniopora n. sp	....	....	×	....	....	....	....	....	....	....	....	....	....	....	×	....	....
Goniopora sp. indet	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....

Miocene fossils from Central Plain, Las Cahobas formation—Continued.

West side of plain—Continued.

Species.	Las Cahobas.																Hinche.
	9909	9773	9906	9905	9910	9772	9988	9911	9774	9775	9776	9777	9916	9927	9928	9783	9944
Brachiopoda:																	
Lingula sp.	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....
Mollusca:																	
Gastropoda:																	
Melongena consors Sowerby ?	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....
Alectrion sp. cf. A. cercadensis Maury	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....
Cerithium ? sp	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....
Potamides ? sp	....	....	×	....	....	×	....	....	....	....	×	....	....	....	....	....	....
Turritella sp.	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....
Fissuridea sp. indet	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....
Pelecypoda:																	
Barbatia sp.	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Scapharca chiriquiensis (Gabb)	....	....	....	....	....	×	....	....	....	....	×	....	....	....	....	....	....
Ostrea cahobasensis Pilsbry and Brown	×	....	....	....	×	....	....	×	×	×	....	....	....	....	....	....	×
Ostrea bolus Pilsbry and Johnson	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....	....
Ostrea haitensis Sowerby	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....
Pecten (Pecten) sp	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Chlamys (Aequipecten) sp	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....
Spondylus sp. cf. S. bostrychites Guppy	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Mytilopsis sp.	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....
Miltha sp.	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Tellina ? sp. indet	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Macoma ? sp. indet	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Tagelus ? sp. indet	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Solen ? sp. indet	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Labiosa ? sp. indet	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Corbula sp.	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....
Corbula (Bothrocorbula) viminea Guppy	....	....	....	....	....	....	....	....	....	....	....	?	....	....	....	....	....

Miocene fossils from Central Plain, Las Cahobas formation—Continued

East side of plain.

Species.	Las Cahobas.	
	9930	9931
Mollusca:		
Gastropoda:		
Cylichnella n. sp. a cf. C. trictumtritonis Maury	?	.....
Ringicula n. sp. c	×	.....
Conus n. sp., also from Baitoa formation	×	.....
Marginella nugax Pilsbry and Johnson	×	.....
Marginella n. sp. a cf. M. maoensis Maury	×	.....
Marginella (Gibberula) sp. b cf. M. chondra Gardner (MSS.)	×	.....
Closia n. sp. a cf. unnamed Gurabo sp	×	.....
Melongena orthocantha Pilsbry and Johnson	.....	×
Alectrion cercadensis Maury	×	.....
Cerithium (Ptychocerithium) sp	×	.....
Potamides n. sp. a cf. P. gastrodon Pilsbry and Johnson	×	×
Potamides sp.	.....	×
Cerithidea sp.	×	.....
Bittium sp. g cf. B. asperoides Gabb	×	.....
Bittium sp. h	×	.....
Alabina sp.	×	.....
Meioceras sp. cf. M. constrictum (Gabb)	×	.....
Fossarus (Isapis) sp	×	.....
Rissoa sp.	×	.....
Hydrobia sp. a	×	.....
Hydrobia sp. b	×	.....
Tryonia sp.	×	.....
Epitonium sp.	×	.....
Turbonilla sp.	×	.....
Odostomia sp. a	×	.....
Phasianella punctata (Gabb)	×	.....
Neritina (Puperita) figulopicta Maury	×	×
Circulus sp.	×	.....
Teinostoma depressum (Gabb)	×	.....
Scaphopoda:		
Cadulus sp.	×	.....
Pelecypoda:		
Nucula tenuisculpta Gabb	×	.....
Leda sp.	×	.....
Scapharca chiriquiensis websteri (Pilsbry)	×	.....
Ostrea sp.	×	×
Phacoides (Phacoides) sp.	×	.....
Phacoides (Parvilucina) sp.	×	.....
Callodardia ? sp	×	.....
Corbula sp. b cf. C. sericea Dall	×	.....

Fossils of Artibonite group.—The collection from station 7544, apparently from the Artibonite group, includes 6 new species of plants, described by Berry,[1] and a new species of fish, described by Cockerell.[2] The fish belongs to *Cichlasoma,* a common genus in the streams of South and Central America and north Africa. Six species of *Cichlasoma* are now

[1] Berry, E. W., Tertiary fossil plants from the Republic of Haiti: U. S. Nat. Mus. Proc., vol. 62, Art. 4, 10 pp., 1 pl., 2 text figs., 1922.

[2] Cockerell, T. D. A., A fossil cichlid fish from the Republic of Haiti: U. S. Nat. Mus. Proc., vol. 63, Art. 7, 2 pp., 1 pl., 1923.

living in Cuba, but none in the other West Indian islands. The Cuban cichlids are evidently remnants of a once widely distributed West Indian cichlid fauna.

Station in Central Plain, Artibonite group (Miocene).

7544 (W 185 F). Arrondissement of Las Cahobas, in cut along road from Mirebalais to Las Cahobas, on north side of ravine at foot of mountains on north side of gap. W. P. Woodring, collector. January 8, 1921.

Miocene fossils from Central Plain, Artibonite group (station 7544).

Fish:
Cichlasoma woodringi Cockerell.
Plants:
Gymnogramme woodringi Berry.
Simaruba haitensis Berry.
Plants—continued:
Mespilodaphne hispaniolana Berry.
Mimusops preparvifolia Berry.
Chrysophyllum cahobasensis Berry.
Bumelia cuneatafolia Berry.

Artibonite Valley and Chaîne des Mateux.

The Miocene beds in the Artibonite Valley and on the Chaîne des Mateux were once probably continuous with those in the Central Plain over the Montagnes Noires. The name Artibonite group is here applied to them. As the outcrop of these beds is almost continuous the fossils obtained from them are given in one list, on pages 217-218.

Artibonite Valley.

Artibonite Valley, as the term is here used, embraces the Artibonite Valley proper and its southeastward prolongation, the valley of Rivière Fer-à-Cheval. In many features it resembles the Central Plain, as it is a deep plunging syncline, modified by secondary folds, containing Miocene rocks. Although the essential stratigraphic features of the Artibonite group of the Artibonite Valley are known, naming of the recognizable rock units would only result in a cumbersome nomenclature.

In the lower part of the Artibonite Valley the Miocene rocks on the northeast side of Rivière Artibonite seem to be concealed by Recent flood-plain deposits and Quaternary dissected terrace gravels downstream from the vicinity of La Chapelle. Miocene rocks lie at the surface on the southwest side of Rivière Artibonite downstream from La Chapelle, and generally on both sides of the river upstream from La Chapelle to Mirebalais except where they are covered by flood-plain deposits.

In the foothills 3 or 4 kilometers southwest of La Chapelle Miocene marls rise to an altitude of 500 or 600 meters above sea level and conformably overlie white, chalky, unfossiliferous limestone of supposed Oligocene age. Both series of rocks dip northeastward at angles of 45° to 75°. A transition from limestone to marl takes place by the intercalation of shaly beds that gradually increase in number and thickness as the beds of white or yellowish unfossiliferous limestone diminish. The thickness of these transition beds is perhaps 100 meters. Above the transition beds are several hundred meters of marl and very fine grained soft sandstone.

The prevailing colors are blue, gray, or yellow. The marl has the typical conchoidal fracture shown in Plate XIV, *C*. The beds are thin but generally very even. These rocks underlie a long lowland extending from Morne Saut d'Eau northwestward beyond Marché Désarmes, parallel to the Artibonite flood plain. In the upper part of this marl-sandstone series there are thin beds of yellowish limestone containing indeterminable casts of corals. The beds of limestone probably increase in number and thickness up to the base of the overlying coralliferous limestone member.

The coralliferous limestone member is massive and has a thickness of perhaps 50 to 100 meters. It forms the ridge that extends from Morne Saut d'Eau northwestward to Marché Désarmes and an unknown distance beyond, and that separates the lowland underlain by the lower marl and sandstone from the flood plain of the Artibonite. (See Pl. XXX, *B*, p. 386.) The coralliferous limestone appears to be at the top of the Miocene section below Morne Saut d'Eau, but farther southeast it is overlain by marl beds like those in underlying part of the section.

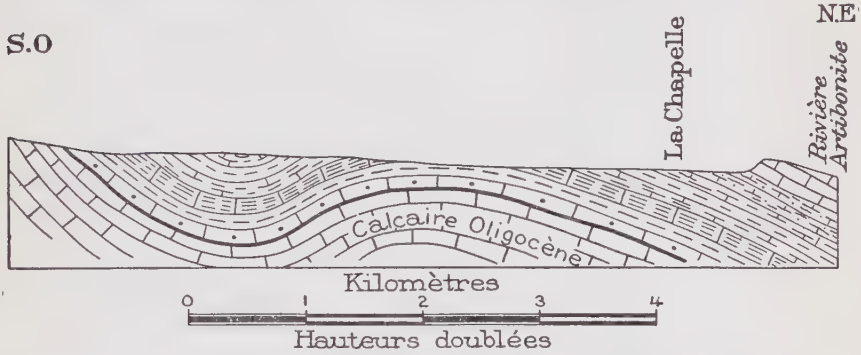


FIGURE 12.—Section of Miocene beds on the south side of Artibonite Valley near La Chapelle, as exposed along Rivière Delean.

Total thickness of Miocene beds about 750 meters.

In the lower valley the strike of the rocks averages about N. 50° W., parallel to the general elongation of the trough. The structure of the Miocene beds on the southwest side of the valley is illustrated in Figure 12, which is based on excellent and almost continuous exposures along Rivière Delean. This limb of the major syncline is modified by a single prominent anticlinal arch, the crest of which has been eroded to the soft marl and sandstone and forms the lowland between the coralliferous limestone ridge and the base of the mountains. The anticline probably rises to the southeast, forming the crest of Morne Saut d'Eau, where the older limestones apparently have been exposed by erosion. The folding on the north flank of Morne Saut d'Eau is far more complex than that in the region to the northwest. The dips at some places are steeper, the strikes are variable in direction, and the beds here and there dip to the southwest. Both on Rivière Delean and on the trail to Couyau the dips steepen at the edge of the mountains, where they range from 45° to 75° NE.

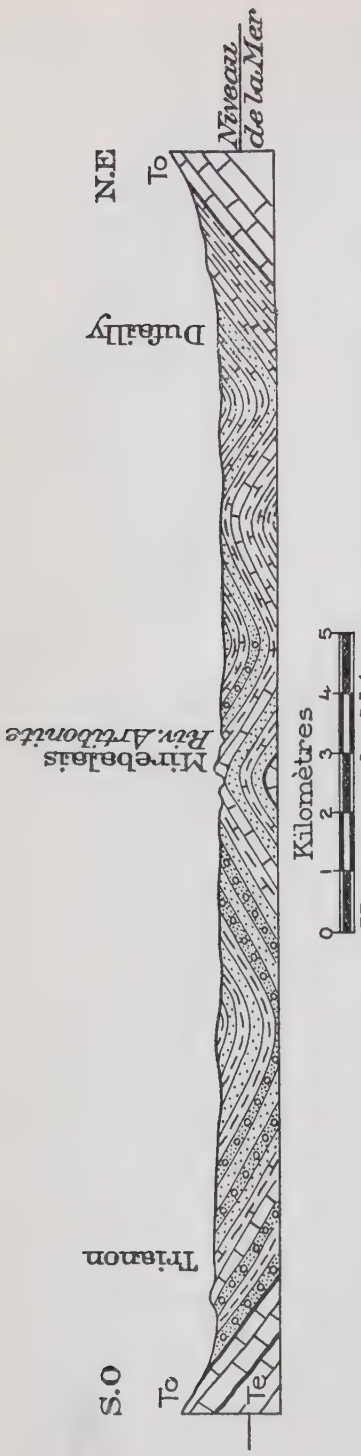


FIGURE 13.—Section of Miocene beds in the upper Artibonite Valley.
To, Oligocene limestone; Te, Eocene limestone.

The thickness of the Miocene beds to the top of the coralliferous limestone member, as estimated from a paced traverse along the Rivière Delean, is about 725 meters. This measurement includes the transition beds at the base.

All the determinable fossils collected in this area were found on the north flank of Morne Saut d'Eau, near the highest part of the trail between La Chapelle and Mirebalais, at an altitude of a little more than 300 meters above sea level. They include fossil leaves, crinoid stems, corals, and mollusks. (See lists, pp. 217-218, stations 7542, 9523, 9494, 9496.)

Rocks of the same age underlie the southeastern part of the Artibonite Valley, but along the south edge of the valley they differ in lithology. The structure of the part of the valley immediately below Mirebalais is shown in Figure 13.

The lowest beds at the edge of the mountains northeast of Dufailly consist of white and yellowish marl. A coral listed on page 217 (station 9920) was collected from float derived from a coralliferous limestone probably a hundred meters above the base of the Miocene series. This coralliferous limestone apparently is the same as that described on page 207, although the thickness of marl below it is less. Upon the coralliferous limestone rest beds of reddish-brown sandy marl and a few thin beds of conglomerate. All these beds dip southwestward

at angles of 30° to 60°. Southwest of Dufailly the trail to Mirebalais crosses the southeastward-plunging crest of an anticline paralleling the main synclinal trough. Northwest of the trail a narrow ridge, probably formed by the coralliferous limestone in the lower part of the Miocene series, encircles the plunging crest. Inside this ridge there is a depression and inside the depression a high jagged ridge composed, probably, of Oligocene or Eocene limestone. Beds of white marl, reddish-brown sandy marl, and marly clay overlie the coralliferous limestone and arch over the crest along the trail.

On the south side of the river a similar anticline plunges southeastward. The coralliferous limestone is on the crest of the anticline immediately south of Mirebalais, where it forms the ridge on which Fort Anglais stands. In a road cut about a kilometer south of Mirebalais the limestone weathers to a yellowish marl containing harder lumps of coralliferous limestone. The corals listed on page 217 (station 9563) were collected at this locality, where the beds dip 20° SW. At Fort Anglais, southeast of Mirebalais, the coralliferous limestone seems to dip northeastward. The corals listed on pages 217-218 were collected on the crest of the ridge at Fort Anglais (station 9922) and on the north slope of the ridge (station 9921). The southeasternmost exposure of this limestone is about 2 kilometers southeast of Mirebalais, on the road to Las Cahobas, where the corals listed on pages 217-218 (station 9901) were obtained.

The beds along the south side of the valley, as exposed along the road between Mirebalais and Port-au-Prince, contain detrital material. Above the coralliferous limestone lie reddish-brown siltstone, rusty brown sandstone, and conglomerate consisting of small pebbles. Similar beds crop out farther southwest, between Mirebalais and Trianon, where they lie in the trough of a syncline. Between Trianon and the mountains the beds have a general northeastward dip, but near the mountains they are crumpled, and some exposures show that the softer beds have been squeezed out of place. The coralliferous limestone crops out about half a kilometer south of Trianon, but here it contains only pieces of *Porites* firmly embedded in hard rock. Farther south the underlying thin beds of clay, sandstone, and conglomerate are well exposed in cuts along the recently relocated road.

Miocene rocks crop out along the road from Mirebalais to Las Cahobas east of the crossing of Rivière Fer-à-Cheval. The upper beds consist of sandy shale, sandstone, and conglomerate. The lower beds, made up of marl and thin beds of limestone, are crumpled near the foot of Morne Michel.

At Savanette, in the valley of Rivière Fer-à-Cheval, the Miocene beds correspond to those in the lower part of the series in the Artibonite Valley proper, consisting of thin beds of marl, marly shale, calcareous sandstone, and limestone. Along the lower slopes of the mountains northeast of

Savanette, on the trail to Belladère, these beds are folded in a very narrow syncline. Immediately west of Savanette they are arched in an asymmetric anticline (see Pl. XXVI, *B*) that extends across the narrow valley and then bends southeastward along the south side of the valley. About 3 kilometers west of Savanette Rivière Fer-à-Cheval flows in a narrow gorge of limestone of supposed upper Oligocene age, but farther northwest the Miocene rocks reappear and beds of sandstone and conglomerate overlie the marl and limestone. These detrital rocks form the northwestern end of the ridge between Rivière Fer-à-Cheval and Rivière Gascogne.

The Miocene series in the valley of Rivière Gascogne consist almost entirely of rather coarse detrital rocks. The lowermost beds exposed, which conformably overlie upper Oligocene limestone on the north flank of the Montagnes du Trou d'Eau, consist of calcareous sandstone containing *Stylophora* (station 9562) and sandy clay. Above these beds lie beds of coarse sandstone, containing lenses of conglomerate, and beds of conglomerate and sandy clay. The pebbles in the conglomerate are small and consist of limestone, chert, and basalt. The mollusks listed on page 218 (station 9455) and an undetermined shark tooth were collected from the conglomerate. On the south side of the valley the rocks are arched in two secondary anticlines.

Chaîne des Mateux near St.-Marc.

The rocks of the Artibonite group bend southeastward around the plunging northwest end of the Chaîne de Mateux and flank most of the southwest slope of this range of mountains. They were examined at the following localities near St.-Marc:

Morne des Guêpes.—The Mornes des Guêpes comprise some low ridges and intervening lowlands of northwestward trend that lie between St.-Marc and the Artibonite Plain. The hills border the northeast side of St.-Marc Bay and extend southeastward for several kilometers, probably continuing without interruption up the Artibonite Valley.

Along the road from St.-Marc to Gonaïves the hills consist of two ridges separated by a lowland about 2 kilometers wide. To the northwest these ridges unite, thus inclosing the lowland in that direction. The drainage escapes to the southwest through a narrow gap into St.-Marc Bay.

The entire lowland is underlain by blue, brown, or yellowish soft Miocene marls. A few thin beds of limestone interbedded with the marl contain casts of corals. Good exposures occur in the principal stream course, a usually dry ravine that is about 10 meters below the lowland surface. The marl is very fine grained and highly calcareous. (See analysis, p. 502.)

The ridge on the northeast side of the lowland is composed of rather soft coralliferous limestone, doubtless the same as that which forms the prominent ridges in the Artibonite Valley farther southeast. (See pp. 207-208.) The rock is fairly well exposed in a cut along the road. The northeast slope of this ridge leading down to the Artibonite Plain is covered by alluvial gravel and boulders.

The ridge southwest of the lowland is composed mainly of the same coralliferous limestone. In this locality it contains many pebbles of the older Eocene limestone, some of them as much as 10 centimeters in diameter, and also beds of calcareous sandstone. At both localities a transition from marl to limestone seems to take place by gradual intercalation of limestone beds.

The northwest end of the Mornes de Guêpes, particularly the slopes leading down to St.-Marc Bay, is covered with a veneer of Quaternary coralliferous limestone, which rests unconformably on the Miocene. This Quaternary limestone probably forms most of the ridge northwest of the lowland area.

The structure of the Mornes de Guêpes is rather simple. The whole region forms the nose of a northwestward-plunging anticline, probably the

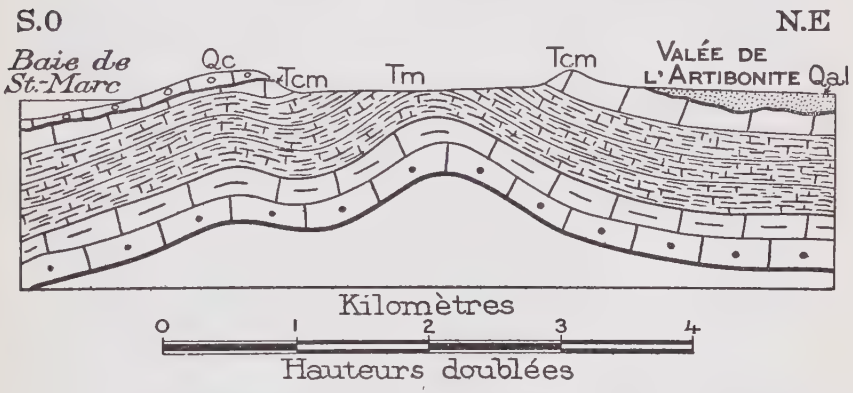


FIGURE 14.—Section across the Mornes des Guêpes.

Qal, Quaternary alluvium; Qc, Quaternary coralliferous limestone; Tcm, Miocene coralliferous limestone; Tm, Miocene marl.

continuation of the anticline on the south limb of the syncline in the Artibonite Valley. (See p. 207.) The lowland underlain by marls is on the crest of this anticlinal nose; the ridges on either side are inward-facing cuestas whose gentler dip slopes lead outward. Figure 14 is a cross section of the fold along the line of the road. The anticline is modified on the southwest limb by a secondary arch. As shown in figure 14, the base of the Miocene is not exposed, but the thickness of the exposed beds is estimated roughly at 315 meters.

Fossils are more or less abundant in all the exposed rocks but most of them are poorly preserved, especially those in the marl beds. At the bridge over the dry ravine near the base of the exposed rocks fossil leaves and mollusks (stations 7543 and 9801) and fossil corals (stations 9897 and 9531) were collected. Mollusks were obtained from the intercalated limestone beds farther southwest (stations 9532, 9533). These fossils are listed on pages 217-218. The corals listed on pages 217-218 (station

9794) were collected from the coralliferous limestone on the ridge northeast of the lowland. The corals in this limestone weather out in loose heaps on the surface of the ground.

South of St.-Marc.—South of St.-Marc there is a region comparable in several features to the Mornes des Guêpes. It comprises an interior lowland inclosed on the southwest, northwest, and northeast by ridges composed principally of coralliferous limestone, through which the drainage flows southward and northward in narrow gaps. In the western part of the lowland is the small undrained lake called Étang Bois-Neuf.

The lowland appears to be underlain entirely by Miocene marl, sandstone, and conglomerate. The ridge to the southwest and northwest is capped mainly if not entirely by Quaternary coralliferous limestone, which unconformably overlies the Miocene beds. To the northeast, however, Miocene coralliferous limestone forms part of the inclosing ridges. The corals listed on page 217 (station 9550) were collected from this limestone.

In the northern part of the lowland the beds dip northeastward. At the southern border of the lowland beds of sandstone and marl, which are well exposed, strike N. 35° W. and dip 35° SW. A few harder beds of sandstone are etched into relief by weathering. This sandstone, when examined under the microscope, is found to contain about 20 or 25 per cent of angular to subangular quartz grains, perhaps 15 per cent of greenish weathered fragments of igneous rock, mostly chloritic material, feldspar, or epidote, and the rest limestone fragments. Gypsum is abundant in this exposure, forming veins along bedding planes and joints, and is also scattered through the sandstone as cementing material. It occurs more sparingly in the exposures farther north. Loose weathered blocks of coralliferous limestone indicate that a cap of this rock formerly covered the ridge here as it now does a short distance to the west.

The Miocene rocks in this area are similar to those in the Mornes des Guêpes and appear to lie on the nose of an anticline, the crest of which trends northwestward. This anticline appears to plunge rather steeply to the northwest.

St.-Marc Valley.—Between the Mornes des Guêpes on the northeast and the similar area just described to the south of St.-Marc an intervening lowland extends southeastward from St.-Marc.

For about 2 kilometers southeast of St.-Marc the lowland is covered with alluvium, but farther southeast soft Miocene rocks, chiefly marl, appear to lie at the surface. Bordering the lowland on the northeast and southwest are hills capped by Miocene coralliferous limestone. Corals were collected from a bluff in this limestone at the stream crossing about 4 kilometers east by south from St.-Marc. (See list, pp. 217-218, station 9497.) The region undoubtedly is occupied by a synclinal trough that plunges northwestward under St.-Marc Bay between plunging anticlines.

Southwest slope of Chaîne des Mateux.

Miocene rocks underlie the foothills on the southwest slope of the Chaîne des Mateux from a locality near the northwest end of the Arcahaie Plain southeastward to the place where the trail from Saut d'Eau through Fond-des-Orangers to Port-au-Prince emerges on the Cul-de-Sac Plain. In the Arcahaie Plain the Miocene rocks are covered by Quaternary alluvial deposits. Southeast of Prince, a railway station about 2 kilometers southeast of Boucassin, the Miocene deposits extend to the sea or are separated from it by a very narrow fringe of alluvium. Southeast of the Sources Puantes the Miocene extends along the northern border of the Cul-de-Sac Plain. These Miocene rocks no doubt formerly extended over the crest of the Chaîne des Mateux and were continuous with the Artibonite group of the Artibonite Valley, but they have since been completely removed from the crest of the mountains by erosion. To the south they probably are continuous under the cover of alluvium with the Miocene rocks along the south edge of the Cul-de-Sac Plain.

At Prince a fine-grained yellowish sandstone is exposed in a roadcut. It contains *Orbiculina* and many broken and indeterminable fragments of mollusks (station 9478).

About 200 meters southeast of this exposure a railway cut has been made by digging down the side of a sea cliff. At the base soft yellowish sandstone and clay strike N. 10° E. and dip 40° SE., the strike being nearly at right angles to the shore. These beds contain abundant flakes of gypsum, some parallel to the bedding, others filling joints transverse to the bedding.

Along the trail from l'Arcahaie to Marché Désarmes beds of Miocene age are exposed from the border of the plain, at an altitude of about 100 meters, up to an altitude of about 400 meters above sea level on the mountain side. Figure 5, page 128, shows the rather complicated structural features and stratigraphic relations at this locality.

A prominent foothill ridge at the border of the plain is composed of rather fine-grained yellowish sandstone containing layers of clay. The first beds seen dip to the northeast, away from the plain, but in a short distance the dip changes to the southwest. Northeast of the sandstone ridge stands another ridge, composed of black basaltic rock, considerably weathered. Whether the basalt is solid rock or is detrital rock composed entirely of igneous fragments is not evident. The field observations suggest that the material is solid rock.

Northeastward beyond the basalt and apparently dipping beneath it are beds of yellowish marl. In a high river bluff below the trail this marl is seen to overlie a considerable thickness of bluish marl such as is typical of the Miocene at numerous localities. On the mountain slope the prevailing dip is steep to the southwest up to an altitude of about 300 meters above sea level, and successively lower beds are exposed. The marl grades

down through a series of interbedded layers of blue clay and limestone into rather thick beds of limestone separated by thin shale partings.

Higher up on the trail the dips reverse, so that two short anticlines, close together, are crossed, and there the beds dip northeastward into the face of the mountain for a considerable distance, so that the section on the lower slope is repeated, and near the summit of a ridge that has an altitude of 410 meters beds of marl dip beneath basalt, which probably is the same as that at the foot of the mountain. The exposure of basalt is not more than 50 or 100 meters in width and caps a narrow ridge. The rock appears to be solid basalt but it is greatly weathered, and the appearance may be deceptive.

Immediately northeast of the basalt lies a hard white limestone, probably of Oligocene age. The bedding at first is indeterminable, but farther up the mountain the dips are to the south or southwest. It seems reasonably certain that the limestone has been thrust over the Miocene as shown in Figure 5. The fault indicated at the border of the plain is not so well established, and this structure might be explained as an overturned fold.

The same Miocene rocks were seen along the trail from Saut d'Eau through Fond-des-Orangers to Port-au-Prince. The crest of the mountains on this trail has an altitude of about 680 meters above sea level. To the south the first Miocene beds crop out on the south slope immediately below the crest. They consist of limestone and yellowish marl containing harder lumps of limestone. These beds apparently are high in the series. Some of the beds of limestone contain corals, and specimens weathered out and lying along the trail were collected. (See list, p. 217, station 9460.) The underlying beds consist of marl and sandy limestone arched over the crest of an anticline south of Source Marissel. About 2 kilometers southeast of Source Marissel the trail crosses a bed of igneous rock, apparently interbedded with the marls and limestones. The rock is greenish and is weathered. It seems to consist entirely of igneous material but contains small, smooth pebbles of rock that have the same appearance as the matrix. It contains also large angular pieces of vesicular basalt. The basalt is apparently overlain by a limestone containing the corals listed on page 217 (station 9461). This limestone probably is the same as the coralliferous limestone near the crest of the mountains. Toward the edge of the Cul-de-Sac Plain thin beds of marl and sandy marl, which dip steeply northeastward, underlie the coralliferous limestone.

Fossils.

The list given on pages 217-218 shows that many corals were collected from the coralliferous limestone, or limestones, in the middle part of the Artibonite group in the Artibonite Valley and on the crest and flanks of the Chaîne des Mateux. Several of the species were also found in the

coralliferous limestones at the base of the Las Cahobas formation in the Central Plain, and the coralliferous limestones in all these regions probably lie at about the same horizon. The collections, like collections of corals from Miocene rocks in the Central Plain, contain *Orbicella imperatoris* Vaughan and *Orbicella canalis* Vaughan, which formerly were thought to be restricted to upper Oligocene deposits.

The collection from station 9494 includes fragmentary crinoid stems that have been examined by Mr. Frank Springer, of the United States National Museum. He has described these remains as *Balanocrinus haitensis* n. sp.[1] The genus *Balanocrinus* is most abundant in Jurassic and Cretaceous deposits, but one species has been described from the Eocene of the Anglo-Parisian basin and another from the Miocene (Helvetian) of Italy. This Haitian crinoid is the first stalked Tertiary crinoid described from the western hemisphere.

The molluscan fauna of these beds is very meager. For some unknown reason, probably environmental conditions, the rich shoal-water fauna of the Thomonde formation was excluded from these regions.

A collection of plants obtained in the Mornes de Guêpes contains the species *Gymnogramme woodringi* Berry, also collected in the Central Plain. Another collection from the same region contains *Pisonia conditi* Berry, described from beds of Miocene or Pliocene age on the north shore of Samaná Bay, Dominican Republic.

Stations in Artibonite Valley and Chaîne des Mateux (Miocene).

7542 (B 139 F). Arrondissement of St.-Marc, trail from La Chapelle to Mirebalais, ravine a kilometer west of divide on trail, about 10 kilometers southeast of La Chapelle, at an altitude of about 300 meters above sea level. J. S. Brown, collector. December 18, 1920.

9523 (B 137 F). Arrondissement of St.-Marc, crest of hill near divide on trail from La Chapelle to Mirebalais. J. S. Brown, collector. December 18, 1920.

9494 (B 138 F). Arrondissement of St.-Marc, divide on trail from La Chapelle to Mirebalais. J. S. Brown, collector. December 18, 1920.

9496 (B 140 F). Arrondissement of St.-Marc, float on slope of hill on trail from La Chapelle to Mirebalais about a kilometer west of divide. J. S. Brown, collector. December 18, 1920.

9920 (W 222 F). Arrondissement of Mirebalais, float on trail from Thomonde to Mirebalais, about 2 kilometers north of Dufailly, at an altitude of 360 meters above sea level. W. P. Woodring, collector. January 18, 1921.

9563 (W 134 F). Arrondissement of Mirebalais, road from Mirebalais to Port-au-Prince, about half a kilometer south of Mirebalais. W. P. Woodring, collector. December 7, 1920.

9921 (W 223 F). Arrondissement of Mirebalais, float on north slope of ridge on which Fort Anglais stands, 0.5 kilometer southeast of Mirebalais, at an altitude of 140 meters above sea level. W. P. Woodring, collector. January 19, 1921.

[1] Springer, Frank, A new Tertiary crinoid in the West Indies: U. S. Nat. Mus. Proc. (Awaiting publication.)

9922 (W 224 F). Arrondissement of Mirebalais, crest of ridge at Fort Anglais about 0.75 kilometer southeast of Mirebalais, at an altitude of 190 meters above sea level. W. P. Woodring, collector. January 19, 1921.

9901 (W 180 F). Arrondissement of Mirebalais, road from Mirebalais to Las Cahobas, float about 2 kilometers east-southeast of Mirebalais, at an altitude of 165 meters above sea level. W. P. Woodring, collector. January 8, 1921.

9941 (W 183 F). Arrondissement of Mirebalais, road from Mirebalais to Las Cahobas, about 4 kilometers east of crossing of Rivière Fer-à-Cheval. W. P. Woodring, collector. January 8, 1921.

9455 (W 131 F). Arrondissement of Mirebalais, trail from Cornillon to Marché Canard, 200 meters south of first crossing of Rivière Gascogne, at an altitude of 325 meters above sea level. W. P. Woodring, collector. December 3, 1921.

9562 (W 129 F). Arrondissement of Mirebalais, trail from Cornillon to Marché Canard, north slope of mountains, about 11 kilometers northwest of Cornillon, at an altitude of 545 meters above sea level. W. P. Woodring, collector. December 4, 1920.

9801 (K 210 F). Arrondissement of St.-Marc, road from St.-Marc to Gonaïves, near bridge across dry ravine about 4 kilometers northeast of St.-Marc. W. S. Burbank, collector. March 30, 1921.

7543 (K 210 F). Same collection as at station 9801.

9897 (B 346 F). Arrondissement of St.-Marc, float at same locality as station 9801. J. S. Brown, collector. March 30, 1921.

9532 (K 51 F). Arrondissement of St.-Marc, same locality as station 9801. W. S. Burbank, collector. December 8, 1920.

9533 (K 52 F). Arrondissement of St.-Marc, road from St.-Marc to Gonaïves, about 3 kilometers northeast of St.-Marc. W. S. Burbank, collector. December 9, 1920.

9531 (K 50 F). Arrondissement of St.-Marc, road from St.-Marc to Gonaïves, just south of crest of divide about 4.5 kilometers northeast of St.-Marc. W. S. Burbank, collector. December 8, 1920.

9794 (W 346 F). Arrondissement of St.-Marc, road from St.-Marc to Gonaïves, north slope of divide about 6 kilometers northeast of St.-Marc. W. P. Woodring, collector. March 27, 1921.

9550 (B 124 F). Arrondissement of St.-Marc, float on road from St.-Marc to Port-au-Prince, south end of gap about 6 kilometers south of St.-Marc. J. S. Brown, collector. December 7, 1920.

9497 (B 142 F). Arrondissement of St.-Marc, trail from St.-Marc to Verrettes, crossing of stream about 3 kilometers east-southeast of St.-Marc. J. S. Brown, collector. December 22, 1920.

9478 (B 118 F). Arrondissement of Port-au-Prince, road from St.-Marc to Port-au-Prince, cut about a kilometer east of Boucassin. J. S. Brown, collector. December 6, 1920.

9460 (W 145 F). Arrondissement of Port-au-Prince, trail from Fond-des-Orangers to the Cul-de-Sac Plain, float on south slope of mountains about a kilometer north of Source Marissel, at an altitude of 635 meters above sea level. W. P. Woodring, collector. December 8, 1920.

9461 (W 148 F). Arrondissement of Port-au-Prince, trail from Fond-des-Orangers to the Cul-de-Sac Plain, south slope of mountains 3 kilometers southeast of Source Marissel, at an altitude of 530 meters above sea level. W. P. Woodring, collector. December 8, 1920.

Miocene fossils from Artibonite Valley and Chaîne des Mateux.

Species.	St.-Marc.				Mirebalais.								St.-Marc.								Port-au-Prince.		
	7542	9523	9494	9496	9920	9563	9921	9922	9901	9941	9455	9562	9801	7543	9897	9532	9533	9531	9794	9550	9497	9478	9460	9461
Foraminifera:																								
Orbiculina sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..
Corals:																								
Stylophora n. sp., also from station 8610, Yaque group, Dominican Republic	..	..	..	..	..	?	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Stylophora sp.	..	..	×	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	×	..	..	..	..	..
Stephanocoenia intersepta (Esper)	..	..	..	×	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Dichocoenia tuberosa Duncan	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..
Dichocoenia stokesi Milne-Edwards and Haime	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Orbicella imperatoris Vaughan	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×
Orbicella sp. cf. O. imperatoris Vaughan	..	×	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..
Orbicella canalis Vaughan	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..
Orbicella n. sp., also from Miocene of Trinidad	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Orbicella sp.	..	..	×	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Orbicella sp. cf. O. annularis (Ellis and Solander)	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Orbicella limbata (Duncan)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..
Orbicella sp. aff. O. altissima (Duncan)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..
Orbicella cavernosa var. endothecata (Duncan)	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Orbicella cavernosa (Linnaeus) var	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..
Orbicella ? sp.	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Solenastrea bournoni Milne-Edwards and Haime	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Solenastrea sp. aff. S. bournoni Milne-Edwards and Haime	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..
Solenastrea hyades (Dana)	..	..	..	×	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Mycetophyllia sp. a	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	?	..	..	..	..
Siderastrea radians (Pallas)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..
Agaricia dominicensis Vaughan	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..
Agaricia sp., also from Gurabo formation and Mao Adentro limestone	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..
Agaricia sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..
Psammocora n. sp. b	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Porites sp. cf. P. porites (Pallas)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	×	..	..	..

Miocene fossils from Artibonite Valley and Chaîne des Mateux—Continued.

Species.	St.-Marc.				Mirebalais.								St.-Marc.								Port-au-Prince.		
	7542	9523	9494	9496	9920	9563	9921	9922	9901	9941	9455	9562	9801	7543	9897	9532	9533	9531	9794	9550	9497	9478	9460	9461
Corals—Continued.																								
Porites furcata Lamarck	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..
Porites sp. aff. P. furcata Lamarck	..	×	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Porites sp. cf. P. astreoides Lamarck	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Porites sp. cf. sp. from Mao Adentro limestone	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..
Goniopora sp. cf. G. jacobiana Vaughan	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Goniopora sp. indet	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..
Crinoid:																								
Balanocrinus haitensis Springer	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Mollusca:																								
Pteropoda:																								
Styliola sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..
Cavolina sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..
Gastropoda:																								
Planorbis ? sp	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Conus sp. indet	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Phos ? sp	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..
Pelecypoda:																								
Nucula sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..
Ostrea sp.	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	×	..	..	..	..	..	..	..
Pecten sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..
Pecten sp. cf. P. pittieri Dall	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Amusium (Pseudamusium) sp	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..
Spondylus sp.	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Mytilopsis sp.	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..
Phacoides (Parvilucina ?) sp	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	×	..	..	..	..	..	..	..	..
Plants:																								
Gymnogramme woodringi Berry	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Pisonia conditi Berry	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..
Simaruba haitensis Berry	?	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

SOUTHERN EDGE OF THE CUL-DE-SAC PLAIN.

General features.—The surface features of the Cul-de-Sac Plain are shown in Plate XXXIX (p. 516), and are described on pages 395-397. Most of the plain, which is relatively smooth throughout, is covered with alluvium, but Miocene rocks are exposed in the foothills that border the mountains on the south. The Miocene rocks are at most places unconformably covered with dissected gravels, probably of Pleistocene age, and are exposed only in ravines and along roads and trails. The exposures were examined at several places, most of them near Port-au-Prince and Pétionville.

Besides containing characteristic fossils, the Miocene series has certain distinctive lithologic and structural features at nearly all the localities examined. The series consists largely of soft, fine-grained grayish sandstone and of bluish marl, in thin, even beds. Beds of harder yellowish

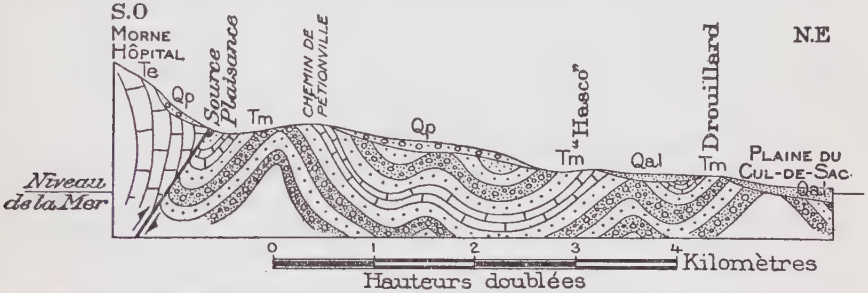


FIGURE 15.—Composite generalized section of Miocene beds along the south side of Cul-de-Sac Plain.

Qal, Quaternary alluvium; Qp, Pleistocene conglomerate; Tm, Miocene; Te, upper Eocene limestone.

limestone and of conglomerate consisting of a mixture of boulders of black basalt and of upper Eocene limestone are conspicuous at some places.

Fossils, especially small mollusks, are moderately abundant in the sandy beds but most of them are poorly preserved. Some of the beds of limestone contain numerous fossils, many of which, however, are only casts.

In nearly every exposure the beds are tilted at steep angles and appear to be crumpled. There is clear evidence of faulting at some places in the foothills where the upper Eocene limestone of the adjacent mountains appears to have been thrust northward over the Miocene beds. (See Fig. 15.)

The thickness of the beds can not be estimated accurately but is doubtless several hundred meters. Although the line of exposures extends nearly parallel to the strike of the beds, a thickness that appears to be at least 200 meters is exposed on the Pétionville road. The "Hasco" well, near Port-au-Prince (see p. 525), penetrated the Miocene to a depth of 141 meters, which, allowing for the dip, indicates a thickness at that place of 100 meters.

Vicinity of Port-au-Prince and Pétionville.—The exposures near Port-au-Prince and Pétionville, which are in hillside cuts made in road grading and are unusually good, are most numerous along the main road from Port-au-Prince to Pétionville, particularly in the first 2 kilometers out of Pétionville, along the southward bend of the road. These and other exposures are shown diagrammatically in Figure 36 (p. 568), a sketch map of the geology of the region near Port-au-Prince. They are not continuous but are isolated. In these exposures the beds strike N. 45° W. to N. 75° W. and dip northward at angles of 30° to 79°. The beds consist of sandstone, conglomerate, and limestone and contain the fossils listed on page 222, stations 9564, 9574, 9573, and 9572.

Miocene beds are well exposed in the Ravine Bois de Chêne just below Source Plaisance at intervals for several hundred meters downstream from the spring, but the full extent of the exposures was not determined. All the dips observed were southward. The beds, which are intimately related to the origin of the spring (see p. 572), are chiefly bluish marl and brownish sandstone. They contain the fossils listed on p. 222 (station 9468).

Three exposures of the Miocene were seen near Source Turgeau. Grayish sandy beds, apparently dipping southward, are exposed in the bed of a deep ravine about 300 meters east of Turgeau. The fossils listed on p. 222 (station 9571) were collected at this locality. At a point about 100 meters east of Turgeau, on a trail, is a poor exposure of sandy beds, apparently like those just mentioned. About 300 meters a little south of west of Turgeau, on a trail leading up Morne Hôpital, is a poor exposure of clayey marl, whose bedding is indistinct but appears to dip southward.

Miocene beds are exposed on the low hill where the houses of the Haytian-American Sugar Co. ("Hasco") are situated, at the north edge of Port-au-Prince and just east of the Arc de Triomphe. The slopes of the hill are covered with soil, but good exposures are found in the ditches along the road leading up to the houses and in pits on the crest of the hill south of the houses. The beds exposed along the road consist of sandstone, clay, marl, and limestone. Fossils were collected at several places along the right side of the road going up the hill. (See list on p. 222, stations 9462, 9463, 9464, and 9750.) Valves of the large plicate oyster *Ostrea haitensis* are strewn on the ground below the first house, and many barnacles may be seen in pockets in the weathered limestone. A pit near the crest of the hill southeast of the club house exposes yellowish limestone interbedded with poorly consolidated conglomerate containing pebbles, as large as a man's fist, of hard white limestone, chert, and weathered basalt. At all these exposures the beds dip steeply southwestward. A well on this hill penetrated Miocene rocks to a depth of 141 meters.

At Drouillard, a railway station on the main road out of Port-au-Prince about 2 kilometers northeast of the Arc de Triomphe, Miocene beds consisting of soft bluish marl and yellow clayey limestone are exposed for about 60 meters in a roadside cut. The beds dip 50° southwestward.

Beds of Miocene age are exposed on the right bank of the Grande Rivière du Cul-de-Sac for a distance of about 400 meters above the Bassin Général. The rocks exposed consist of bluish marl, grayish sand, and thin beds of limestone. The prevailing dip is 30° to 60° N. At the south end of the exposure the beds are in fault contact with upper Eocene limestone, and near the contact they are crumpled. The mollusks listed on page 222 (stations 9578 and 9590) were collected from these beds.

There is every reason to believe that the Miocene beds underlie the alluvium throughout the plain. Wells at La Morinière and Dessources penetrate more than 100 meters of beds classified from the logs as Miocene (see pp. 521-522).

Fossils.—The fossils collected from the Miocene beds along the south side of the Cul-de-Sac Plain comprise a variety of organisms. The corals are poorly preserved but include typical Miocene species. *Echinoneus cyclostomus* Leske, picked up loose on the hill where the houses of the Haytian-American Sugar Co. stand, is the only post-Eocene echinoid obtained in the Republic. This Recent species has been found in deposits as old as the Anguilla formation.[1] The largest collection of mollusks made, obtained from a bed of limestone on the same hill (station 9464), contains many specimens of *Ostrea haitensis,* the large plicate oyster found also in the Thomonde and Las Cahobas formations of the Central Plain and in the Gurabo formation of the Dominican Republic. Several Pectens and Veneroids found at this locality are very similar to Bowden species. Pteropods are abundant in some of the beds exposed on the Pétionville road and on the Grande Rivière du Cul-de-Sac. Some of the pteropods listed as "*Tentaculites*" sp. are remarkably similar to the Paleozoic *Tentaculites.* They have not been studied critically but are probably similar to the so-called *Tentaculites* obtained from the Oligocene of Germany by Ludwig and by Blankenhorn.

These Miocene beds seem to be younger than the Artibonite group of the Central Plain and Artibonite Valley and are correlated with the Gurabo formation of the Dominican Republic, which is considered Helvetian. The Cerros de Sal formation, at the east end of the trough of which the Cul-de-Sac Plain is a part, seems to be even younger.

Stations along south edge of Cul-de-Sac Plain (Miocene).

9654 (W 12 F). Arrondissement of Port-au-Prince, road from Port-au-Prince to Pétionville, about 1.5 kilometers from Pétionville. W. P. Woodring and J. S. Brown, collectors. October 9, 1920.

9574 (B 18 F). Arrondissement of Port-au-Prince, road from Port-au-Prince to Pétionville, about 2 kilometers from Pétionville. J. S. Brown, collector. October 12, 1920.

[1] Jackson, R. T., Fossil Echini of the West Indies: Carnegie Inst. Washington Pub. 306, pp. 54-55, pl. 9, figs. 4, 5, 1922.

Miocene fossils, south edge Cul-de-Sac Plain, arrondissement of Port-au-Prince.

Species.	9654	9574	9573	9572	9468	9571	9462	9463	9464	9750	9590	9578
Foraminifera:												
Sorites sp. cf. S. americana (Cushman)	..	..	..	×	..	..	..	..	..	..	..	..
Corals:												
Stylophora sp.	..	..	×	..	..	..	..	..	..	..	..	..
Asterosmilia sp.	..	×	..	..	..	..	..	..	..	..	..	..
Stephanocoenia intersepta (Esper)	..	×	..	..	..	..	..	..	..	..	..	..
Solenastrea hyades (Dana)	..	..	..	..	..	..	..	..	×	..	..	..
Agaricia dominicensis Vaughan	..	..	×	..	..	..	..	..	..	..	..	..
Porites sp. cf. P. astreoides Lamarck	..	×	..	..	..	..	..	..	..	..	..	..
Echini:												
Echinoneus cyclostomus Leske	..	..	..	..	..	..	..	..	..	×	..	..
Bryozoa:												
Hemiseptella sp.	..	..	..	..	..	..	×	..	..	..	..	..
Puellina radiata Moll	..	..	..	..	..	..	..	..	×	..	..	..
Holoporella albirostris Smitt	..	..	..	..	..	..	..	..	×	..	..	..
Mollusca:												
Pteropoda:												
Cavolina sp. cf. C. digitata (Guppy)	×	×	..	..	..	..	..	..	..	..	..	..
Cavolina sp.	..	..	..	..	×	×	..	..	..	..	..	..
"Tentaculites" sp.	..	×	..	..	..	×	..	..	..	..	..	..
Gastropoda:												
Actaeon sp. cf. A. textilis Guppy	..	..	..	..	..	..	..	..	..	..	..	×
Bullaria sp.	..	..	..	..	..	..	..	..	×	..	..	..
Oliva sp.	..	..	..	..	..	..	..	..	×	..	..	..
Marginella sp.	..	..	..	..	..	..	..	×	..	..	..	..
Alectrion sp.	..	..	..	..	..	..	..	×	..	..	..	..
Murex (Phyllonotus) pomum Gmelin	..	..	..	..	..	..	..	..	..	×	..	..
Sconsia sp.	×	..	..	..	..	..	..	..	..	..	..	..
Pyrula sp.	..	..	..	..	..	..	..	..	×	..	..	..
Calyptraea sp.	..	..	..	..	..	..	..	..	×	..	..	..
Xenophora conchyliophora Born ?	..	..	..	..	..	..	..	..	×	..	..	..
Pelecypoda:												
Barbatia (Acar) sp. cf. B. (A.) domingensis (Lamarck)	..	..	..	..	..	..	..	×	..	..	..	..
Scapharca sp. cf. S. halidonata Dall	..	..	..	..	..	..	..	×	..	..	..	..
Ostrea haitensis Sowerby	..	..	..	..	..	..	..	..	×	..	..	..
Ostrea sp.	..	..	..	..	..	..	×	..	..	..	..	..
Chlamys (Aequipecten) sp. cf. C. (A.) uselmae Pilsbry and Johnson	..	..	..	..	..	..	×	..	×	..	..	..
Chlamys (Aequipecten) sp. cf. C. (A.) pleuronominis Pilsbry and Johnson	..	..	..	..	..	..	×	..	×	..	..	..
Chlamys (Aequipecten) sp.	..	..	..	..	..	..	..	..	..	×	..	..
Plicatula ? sp.	..	..	..	..	..	..	..	..	×	..	..	..
Placuanomia sp.	..	..	..	..	..	..	..	..	×	..	..	..
Crenella sp.	..	..	..	..	..	..	×	..	..	..	..	..
Modiolus ? sp.	..	..	..	..	..	..	..	..	×	..	..	..
Modiolaria ? sp.	..	..	..	..	..	..	..	..	..	..	..	×
Lithophaga sp.	..	..	..	..	..	..	..	..	×	..	..	..
Chama sp. cf. C. macerophylla Gmelin	..	..	..	..	..	..	..	..	×	..	..	..
Cardium (Trachycardium) sp.	..	..	..	..	..	..	..	..	×	..	..	..
Cardium (Papyridea) sp. cf. C. (P.) bulbosum Dall	..	..	..	..	..	..	×	..	..	..	..	..
Antigona (Ventricola) sp. cf. A. (V.) blandiana (Guppy)	..	..	..	..	..	..	×	..	?	..	..	..
Chione (Lirophora) sp. cf. C. (L.) hendersoni Dall	..	..	..	..	..	..	..	..	×	..	..	..
Pitar ? sp.	..	..	..	..	..	..	..	..	×	..	..	..
Petricola ? sp.	..	..	..	..	..	..	..	..	..	..	..	×
Macoma ? sp.	..	..	..	..	×	..	..	..	..	..	..	..
Semele sp. cf. S. sulcata Dall	..	..	..	..	..	..	×	..	?	..	?	..
Cirripedia:												
Balanus sp. cf. B. eburneus Gould	..	..	..	..	..	..	..	..	×	..	..	..
Balanus concavus esepatus Pilsbry	..	..	..	..	..	..	..	..	×	..	..	..
Balanus polyporus Pilsbry	..	..	..	..	..	..	..	..	..	×	..	..

9573 (B 17 F). Arrondissement of Port-au-Prince, road from Port-au-Prince to Pétionville, about 100 meters farther from Pétionville than 9574. J. S. Brown, collector. October 12, 1920.

9572 (B 14 F). Arrondissement of Port-au-Prince, road from Port-au-Prince to Pétionville, about 300 meters farther from Pétionville than 9573. J. S. Brown, collector. October 12, 1920.

9468 (B 21 F). Arrondissement of Port-au-Prince, Ravine Bois de Chêne, just below Source Plaisance. J. S. Brown, collector. October 12, 1920.

9571 (B 13 F). Arrondissement of Port-au-Prince, 300 meters east of Source Turgeau. J. S. Brown, collector. October 11, 1920.

9462 (W 149 F). Arrondissement of Port-au-Prince, road leading up hill to houses of Haytian-American Sugar Co.; altitude 60 meters above sea level. W. P. Woodring, collector. December 14, 1920.

9463 (W 150 F). Arrondissement of Port-au-Prince, road leading up hill to houses of Haytian-American Sugar Co.; altitude 70 meters above sea level. W. P. Woodring, collector. December 14, 1920.

9464 (W 151 F). Arrondissement of Port-au-Prince, road leading up hill to houses of Haytian-American Sugar Co., in long cut on right side of road just below first house; altitude 75 meters above sea level. W. P. Woodring, collector. December 14, 1920.

9750 (B 358 F). Arrondissement of Port-au-Prince, float on hill on which houses of Haytian-American Sugar Co. are located. J. S. Brown, collector. April 11, 1921.

9590 (W 29 F). Arrondissement of Port-au-Prince, right bank of Grande Rivière du Cul-de-Sac about 300 meters above Bassin Général. W. P. Woodring, collector. October 15, 1920.

9578 (B 26 F). Arrondissement of Port-au-Prince, right bank of Grande Rivière du Cul-de-Sac, about 400 meters above Bassin Général, at fault contact. J. S. Brown, collector. October 15, 1920.

North Coast of Southern Peninsula.

Miocene rocks were recognized at a number of places on the north coast of the Southern Peninsula, chiefly in the region between Port-au-Prince and Petit-Goave, along the main highway following the coast. The rocks consist generally of soft sandy or clayey beds, but grade into conglomerate at one extreme or into limestone at the other. As a rule they are tilted and folded. They doubtless form part of a series of marginal marine beds that were continuous westward from the Cul-de-Sac Plain, but are now either submerged or concealed by later deposits along most of the coast. As only small isolated exposures were observed at most localities the details of their stratigraphy can not be given.

Morne-à-Bateau.—Morne-à-Bateau, about 2 kilometers east of the village of Gressier and midway between Port-au-Prince and Léogane, is a small hill at the base of low limestone mountains. In a road cut on the point of the hill there is an exposure of soft yellowish sandy and clayey beds which dip a few degrees westward. The beds contain numerous specimens of the few mollusks listed on page 225, station 9480. The age of the beds is not evident; they may be Pliocene or Quaternary rather than Miocene.

L'Acul.—At the southwest corner of the Léogane Plain, less than a kilometer from a little valley and settlement, both called l'Acul, the road crosses a low ridge in which a poorly consolidated conglomerate is exposed. This conglomerate contains boulders of Eocene limestone and large lumps of material carrying corals and other fossils that apparently resemble Miocene species. At the little stream of l'Acul a collection of similar fossils, clearly of Miocene age, was taken from a pile of loose limestone boulders by the roadside (see list, p. 225, station 9481). The source of the boulders is unknown, but they doubtless came from no great distance.

Grand-Goave.—Some low hills rise from the little alluvial plain of Grand-Goave just south of the road and about a kilometer east of the town. Here soft yellowish and brownish sandstone is exposed in a roadside cut. The bedding is not apparent, but the rocks are cut by numerous fracture planes, which are filled with an unidentified salt, probably alkaline. The rocks contain the fossils listed on p. 225, station 9540.

Blocks of cavernous coralliferous limestone have slumped down from the slope above. They may possibly be Miocene but more probably belong to the Quaternary limestone that is well developed farther east.

Tapion du Petit-Goave.—Miocene rocks underlie a narrow trough between Tapion du Petit-Goave and the mountains to the south. The eastern part of the trough drains eastward and the western part drains westward from a divide which has an altitude of about 182 meters above sea level. On both sides of the divide, for a distance of about 2 kilometers along the road, exposures of the Miocene are common.

The first exposure at the eastern entrance to the trough-like valley is a bluff of coralliferous limestone, probably of Miocene age. The rock is greatly weathered, so that the bedding is not apparent. From this exposure to the top of the divide, a distance of about a kilometer, the rocks in numerous roadcuts consist mainly of brown calcareous sandstone, shaly beds, and angular boulders of basalt and limestone. These beds are unfossiliferous and appear to be nonmarine, at least in part. The prevailing strike is about N. 65° W. and the dip is 40° to 60° NE.

West of the divide the surface is covered by gravel for a few hundred meters, but farther west there are more exposures of the sandy and conglomeratic beds. The beds are folded and show minor faulting and slickensiding. About a kilometer west of the divide limestone is interbedded in the conglomerate in beds striking about N. 60° W. and dipping 30° NE. The corals listed on page 225 were obtained from the conglomerate (station 9953) and from the limestone interbedded in the conglomerate (station 9954).

In this locality the Miocene is unconformably overlain by a younger coralliferous limestone, probably of Pliocene age, which at some places is difficult to distinguish from the limestone in the Miocene series.

As the road in this area is nearly parallel to the strike of the rocks no estimate of the thickness of beds can be made; probably only a small part of the section is exposed.

Near Baradères.—Near Baradères, on the trail between Petit-Trou de Nippes and Baradères, there are a few exposures of rocks that are doubtfully referred to the Miocene. Exposures of a fairly consolidated bedded tilted conglomerate were noted 5 or 6 kilometers east of Baradères, in an area underlain chiefly by basalt. The conglomerate contains pebbles of basalt and of the limestone that was assumed to be the upper Eocene limestone of this vicinity.

Beds of soft chalky, unfossiliferous marl are exposed for 200 meters or more along the trail in a small valley about 3 kilometers east of Baradères. If these beds are Miocene they represent remnants preserved by faulting or folding during the uplift and erosion of the surrounding mountains.

Fossils.—The few fossils obtained from the scattered outcrops of Miocene beds along the north coast of the Southern Peninsula indicate that these beds are of about the same age as the Miocene along the south side of the Cul-de-Sac Plain.

Miocene fossils from north coast of Southern Peninsula.

Species.	9480	9481	9540	9953	9954
Foraminifera:					
Orbiculina sp	....	....	×	....	....
Corals:					
Stylophora monticulosa Vaughan (MS.)	....	....	....	....	×
Stylophora sp. a	....	×	....	....	....
Orbicella annularis (Ellis and Solander)	....	....	....	×	....
Mycetophyllia sp.	....	×	....	....	....
Porites sp. indet	....	....	....	×	....
Mollusca:					
Gastropoda:					
Conus sp. cf. unnamed Cercado species	....	×	....	....	....
Murex sp.	....	....	×	....	....
Strombus sp. cf. S. chipolanus Dall	....	....	×	....	....
Cerithium sp.	....	×	....	....	....
Torinia sp. cf. T. rotunda Gabb	....	×	....	....	....
Pelecypoda:					
Scapharca sp.	....	....	×	....	....
Ostrea sp.	×	....	....	....	....
Chlamys (Aequipecten) sp. cf. C. (A.) uselmae Pilsbry and Johnson	....	....	×	....	....
Chlamys (Aequipecten) sp.	×	....	....	....	....
Cardium (Laevicardium ?) sp.	....	....	×	....	....
Metis sp. cf. M. chipolana Dall	....	....	×	....	....
Semele sp. cf. S. sulcata Dall	....	×	....	....	....
Cirripedia:					
Balanus amphitrite Darwin	×	....	....	....	....

Stations on north coast of Southern Peninsula (Miocene).

9480 (K 2 F). Arrondissement of Léogane, cut along road from Port-au-Prince to Léogane at foot of Morne-à-Bateau, about 2 kilometers east of Gressier. W. S. Burbank, collector. October 21, 1920.

9481 (K 3 F). Arrondissement of Léogane, road from Port-au-Prince to Léogane, from boulders at crossing of Rivière l'Acul. W. S. Burbank, collector. October 22, 1920.

9540 (B 31 F). Arrondissement of Léogane, road from Léogane to Miragoâne, about a kilometer east of Grand-Goave. J. S. Brown, collector. October 23, 1920.

9953 (W 348a F). Arrondissement of Léogane, road from Léogane to Grand-Goave, west slope of Tapion du Petit-Goave; from conglomerate. W. P. Woodring and J. S. Brown, collectors. April 10, 1921.

9954 (W 348b F). Arrondissement of Léogane, same locality as 9953 but from limestone interbedded with conglomerate. W. P. Woodring and J. S. Brown, collectors. April 10, 1921.

COMMUNE OF JÉRÉMIE.

Grande Rivière and Bras-à-Droit.—Miocene rocks occupy two areas that form small but prominent interior lowlands southwest of Jérémie, one along the course of the Grande Rivière de Jérémie and the other on its tributary, the Bras-à-Droit. The center of the larger area, the one on the Grande Rivière de Jérémie, is about 7 kilometers southwest of Jérémie, near the village of Tissier. In the southwest part of the area is the large market called Mafron. This lowland measures about 3 kilometers from north to south and at least 7 or 8 kilometers from east to west. The smaller area is about 22 kilometers west-southwest of Jérémie and contains the large market called Chambellan. Its length from east to west is about 4 kilometers, and its width is probably less than 2 kilometers.

The two lowlands were traversed hurriedly and were examined only near the trail. Much of the area in each lowland is covered by thin alluvial deposits, so only a few exposures of the underlying rocks were found. The full extent of the Miocene, which undoubtedly underlies most of each lowland, is inferred from the surface features, which contrast strongly with those of the surrounding limestone areas.

From the few exposures examined it appears that the Miocene rocks in both areas are very similar and consist largely of highly calcareous brown marl and of brown or yellow sandstone, together with some conglomerate. Many conspicuous low hills and ridges in the large area, which trend nearly east and west, appear to be composed of the harder conglomeratic beds.

Marine fossils and strand plants of Miocene age were obtained in the larger area (see lists on p. 228; stations 9992 and 7541). Similar but indeterminable remains of fossil plants were obtained in the smaller area. These fossils indicate that the Miocene sea extended far up the region that now constitutes the valley of the Grande Rivière de Jérémie and perhaps covered a great part of the peninsula.

Wherever the bedding is apparent the Miocene beds are steeply tilted. All the observed dips are to the north or northwest. It seems likely that

the larger area is bounded on the north by a thrust fault. At this northern boundary a very steep and regular escarpment of upper Eocene limestone rises from 200 to 300 meters above the lowland. The nearest observed Miocene beds, several hundred meters south of the escarpment, dip northward, apparently beneath the ridge. Although this is only a single exposure it appears to represent one of the prominent east and west ridges, the profile of which shows that it is a cuesta having a dip slope to the north. This ridge and other northward-dipping ridges do not reappear between the observed exposure and the base of the escarpment, as would be expected if the rocks are in a synclinal trough. The inference is that they plunge beneath the limestone.

The structural relations of the smaller area are more obscure. It, too, is bordered by a steep limestone slope on the north, and the single observed dip, at a point not more than 500 meters south of the ridge, is 37° N., suggesting a relation similar to that in the larger area. However, the dips observed in the Eocene limestone just east of the area seem to indicate a simple syncline along the axis of this lowland, and possibly the Miocene beds merely occupy the trough of a steeply folded syncline.

South of Les Roseaux.—Numerous apparently authentic reports obtained at Jérémie indicate that there are beds of lignite at a place a few kilometers south of Les Roseaux. As lignite in the Republic of Haiti, so far as known, is found only in the Miocene formations there is probably an area of Miocene rocks in that locality. Possibly, however, it may be merely the eastward extension of the lowland on the Grande Rivière de Jérémie.

Fossils.—The marine fossils obtained at station 9992 are poorly preserved but indicate that the beds are of Miocene age, probably lower or middle Miocene. The strand plants *Gymnogramme woodringi* Berry and *Guettardia cookei* Berry, were collected at station 7541. *Gymnogramme woodringi* is also recorded from the lower part of the Artibonite group of the Artibonite Valley and from the Artibonite group of the Central Plain. *Guettardia cookei* was described from beds of Miocene or Pliocene age on the north shore of Samaná Bay, Dominican Republic.

Stations in Commune of Jérémie (Miocene).

9992 (B 96 F). Arrondissement of Grand 'Anse, trail from Jérémie to Moron, about a kilometer east of Tissier and about 6 kilometers from Jérémie. J. S. Brown, collector. November 18, 1920.

7541 (B 95 F). Arrondissement of Grand 'Anse, valley of Grande Rivière de Jérémie, trail between Mafron and Fondelet markets, half a kilometer south of Mafron and about 10 kilometers southwest of Jérémie. J. S. Brown, collector. November 18, 1920.

Miocene fossils from Commune of Jérémie (station 9992).

Foraminifer:
  Sorites sp. cf. S. americana (Cushman).
Coral:
  Porites sp. indet.
Mollusca:
  Gastropoda:
    Oliva sp. cf. O. testacea Lamarck.
    Olivella sp.
    Bittium ? sp.
    Liotia ? sp.
    Neritina sp.
  Pelecypoda:
    Arca sp. cf. A. bowdeniana Dall.
    Cardium (Laevicardium) sp. cf. C. (L.) venustum Gabb.

Miocene fossil plants from Commune of Jérémie (station 7541).

Gymnogramme woodringi Berry.
Guettardia cookei Berry.

Between Port-Salut and Port-à-Piment.

Three exposures of limestone, probably of Miocene age, were noted on the trail between Port-Salut and Port-à-Piment. Two exposures are on either side of Anse-à-Drick; the third is about a kilometer southeast of Damassin. The rock is a rather massive limestone, less dense than the common massive upper Eocene and at most places containing numerous poorly preserved corals, although only one identifiable specimen, a *Pocillopora* similar to *P. arnoldi* Vaughan, was obtained (station 9477). The limestone north of Anse-à-Drick contains undetermined calcareous algae. These exposures seem to indicate a belt of Miocene limestone intervening between the Quaternary coralliferous limestone and the higher mountains of upper Eocene limestone.

Station between Port-Salut and Port-à-Piment (Miocene).

9477 (B 72 F). Arrondissement of Coteaux, trail from Port-Salut to Port-à-Piment, about a kilometer southeast of Damassin. J. S. Brown, collector. November 11, 1920.

Miocene coral from station 9477.

Pocillopora sp. cf. P. arnoldi Vaughan.

Asile Valley.

The Asile Valley is an interior lowland similar in many respects to the lowlands of the commune of Jérémie. The valley stretches from east to west and is about 3 kilometers wide and about 12 kilometers long. On its west side it rises into a plateau of undetermined extent. The town of l'Asile is in the central part of the valley.

Virtually all the Asile Valley seems to be underlain by Miocene rocks, although a large part of the surface is covered with alluvial deposits and the Miocene crops out only in stream bluffs, along trails, or on isolated hills.

In all the valley proper, that part east of the plateau, the exposed Miocene rocks consist of soft, fine-grained sediments that were laid down in lakes or fresh-water swamps. White or cream-colored marl is the predominating rock near l'Asile. In the east and west ends of the valley the sediments contain more clay and in places consist almost entirely of greenish or yellowish clay. Thin seams of black carbonaceous clay are interbedded with the clay and marl. In the western part of the valley the carbonaceous beds contain less clay and consist of impure lignite.

These beds of lignite in the Asile Valley have been mentioned in many publications and have been the object of several mining concessions and some special investigations, but none of the beds observed could ever be of commercial value, and the existence of more promising beds seems very doubtful.

Beds of gravel crop out in the western part of the valley, and coarse angular conglomerate underlies the plateau to the west. The conglomerate and gravel appear to be composed mainly of fragments of limestone, and none of the basalt that is common in the vicinity was found in the exposures observed. The beds of conglomerate are believed to represent a delta deposit formed at the border of the lakes and swamps in which the fine-grained beds were deposited and probably grade into the finer beds on the east. The conglomerate may, however, be really younger than the Miocene beds.

The fine-grained clayey and calcareous sediments are very fossiliferous at certain horizons and contain many small fresh-water mollusks.

The beds in the central and eastern part of the area are generally slightly folded and dip to the south or southwest. Those in the western part of the valley are nearly horizontal. The conglomerate in the plateau seems to dip gently eastward.

The relation of the Miocene to the older rocks was not determined, most of the contacts being covered by alluvium. Undoubtedly the Miocene was deposited on a floor of Eocene limestone and consists partly of material eroded from it. It doubtless also overlies the basalt, although no basaltic débris was observed in the Miocene.

The broader structural relations of the Asile Valley also are obscure. The only observed contact of the Miocene and the older rocks, on the trail to Aquin at the southeast edge of the valley, probably is a fault contact. On the ascent from the Rivière Serpent the Miocene beds, which dip to the southwest, are succeeded by supposed upper Eocene limestone striking N. 65° E. and dipping 72° NW.; these in turn are succeeded abruptly by a narrow band of Miocene and finally by older limestone, most of it of upper Eocene age. West of this locality the southern border of the

valley is formed by a steep escarpment of limestone several hundred meters high. The northern border of the valley is less precipitous and is apparently largely occupied by basalt.

The mountains south of this valley have probably been elevated since the Miocene beds were deposited. The structural relations may then be comparable to those suggested for the lowland at Camp Perrin (see p. 236), and the mountain wall to the south may have been uplifted either by folding or faulting, more likely both.

An exposure of the Miocene beds on the south bank of Rivière Serpent, between Rivière Goudet and Source Paul, about 5 kilometers southeast of the town of l'Asile, shows the following section:

Section of fresh-water Miocene beds on Rivière Serpent.

	Meters.
Alluvium	2
Unconformity.	
6. Clay, yellowish	3.30
5. Clay, black, carbonaceous	.16
4. Clay, yellowish, containing subangular pebbles as large as peas and a little carbonaceous material	.53
3. Clay, black, carbonaceous	.18
2. Clay, grayish buff with darker streaks of carbonaceous material containing carbonized fragments of wood and stems	.20
1. Not exposed	.30
Stream level.	
Thickness of Miocene beds	4.69

The beds strike N. 45° W. and dip 25° SW.

Beds of soft buff to white marl containing numerous fresh-water mollusks were examined at several localities farther northwest along Rivière Serpent. (For list of fossils see p. 231; stations 9519, 9618, and 9619.) Similar fossiliferous marl is exposed on the south bank of Rivière des Pins just north of l'Asile (stations 9617 and 9655).

The following section was measured on the west bank of Rivière la Hotte about 4 kilometers west of l'Asile on the trail to Les Cayes:

Section of fresh-water Miocene beds on Rivière la Hotte.

	Meters.
Top of bluff.	
7. Clay, greenish	4.50
6. Marl, soft, buff colored; station 9621	.36
5. Lignite, soft	.03
4. Marl, soft, yellowish	.15
3. Impure lignite grading downward into black clay	.15
2. Clay, black, grading downward into green clay	1
1. Concealed	2
Bed of stream.	
	8.19

The beds are approximately horizontal. Similar beds crop out farther southwest along the stream.

In the plateau west of the lower valley, near the edge of the mountains, on the trail to Les Cayes, beds of coarse reddish conglomerate are exposed in the steep bluffs of Rivière la Hotte. Limestone cobbles from 15 to 30 centimeters in diameter are abundant. Fragments of chert are common, and there is some fine sand. The beds seem to dip several degrees eastward. Similar conglomerate is found along the trail for some kilometers, but is very poorly exposed.

Fossils.—The fossils obtained from the Miocene beds of the Asile Valley are fresh-water mollusks and fruits of *Chara,* described by Berry as *Chara woodringi.* A similar Miocene fresh-water molluscan fauna is not known in the West Indies. The two species of *Planorbis* are abundant at stations 9519 and 9619. At several localities the marls contain innumerable specimens of *Hydrobia.*

Stations in Asile Valley (nonmarine Miocene).

9519 (W 96 F). Arrondissement of Nippes, trail leading eastward from l'Asile, between Rivière Goudet and Source Paul. W. P. Woodring, collector. November 16, 1920. Also United States Geological Survey fossil plant station 7555.

9618 (B 42 F). Arrondissement of Nippes, north bank of Rivière Serpent a little more than a kilometer east of l'Asile. J. S. Brown, collector. October 31, 1920.

9619 (B 44 F). Arrondissement of Nippes, east bank of Rivière Serpent just above junction with Rivière des Pins, about a kilometer northeast of l'Asile. J. S. Brown, collector. October 31, 1920.

9617 (B 41 F). Arrondissement of Nippes, south bank of Rivière des Pins, just north of l'Asile, at crossing of trail to Anse-à-Veau. J. S. Brown, collector. October 29, 1920.

9555 (W 99 F). Arrondissement of Nippes, same locality as 9617. W. P. Woodring, collector. November 17, 1920.

9620 (B 45 F). Arrondissement of Nippes, south bank of Rivière des Pins, about a kilometer west of l'Asile. J. S. Brown, collector. November 1, 1920.

9621 (B 46 F). Arrondissement of Nippes, west bank of Rivière la Hotte, about a kilometer above junction with Rivière des Pins, and about 3 kilometers west of l'Asile. J. S. Brown, collector. November 1, 1920.

Nonmarine Miocene fossils from Asile Valley, arrondissement of Nippes.

Species.	7555	9519	9618	9619	9617	9555	9620	9621
Mollusca:								
Gastropoda:								
Planorbis sp. a	....	×	....	×	×	....	....	×
Planorbis sp. b	....	×	....	×	....	....	....	....
Hydrobia sp.	....	×	....	×	....	×	....	×
Physa sp.	....	....	....	×	....	....	....	×
Pelecypoda:								
Pisidium sp.	....	....	×	....	....	....	×	....
Plant:								
Chara woodringi Berry	×	....	....	....	....	....	....	....

Camp Perrin.

Nonmarine lignite-bearing beds of Miocene age underlie a large interior lowland near Camp Perrin. In many features this lowland resembles the Asile Valley and the smaller lowlands in the commune of Jérémie. The beds consist of conglomerate, sandstone, shale, lignite, marl, and limestone. Their distribution with reference to the older rock formations is shown in Figure 16. The Miocene rocks are covered by alluvial gravels over almost the entire lowland and are exposed at places along the principal streams and deep ravines. The most complete section examined is on La Ravine du Sud, where good exposures extend almost continuously from a locality about 600 meters north of the diversion dam of the Canal

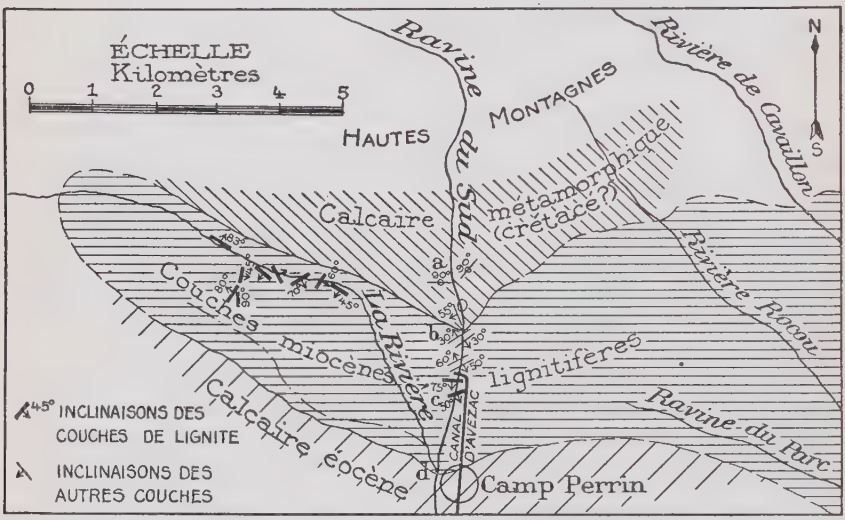


Figure 16.—Sketch map of the lignite area near Camp Perrin.

Base from map of engineers of the Department of Public Works. See Fig. 17 for section along line *a—b—c—d*.

d'Avezac downstream to a locality about 250 meters south of the dam. A section of the beds measured is given on page 234. The thickness of most of the lignite beds was measured, but the thickness assigned to the other beds is based on the width of outcrop as determined by pacing. Figure 17 shows the structural relations of these beds.

The exposures along La Rivière and some tributary ravines were examined for a distance of 2 kilometers at a locality about 4 or 5 kilometers northwest of Camp Perrin. The beds consist of sandy clay, marl, and lignite and closely resemble the beds in the upper part of the section on La Ravine du Sud. As the strike of the beds is approximately parallel to the course of the river, no great thickness is exposed. The base of the series was not found in this area.

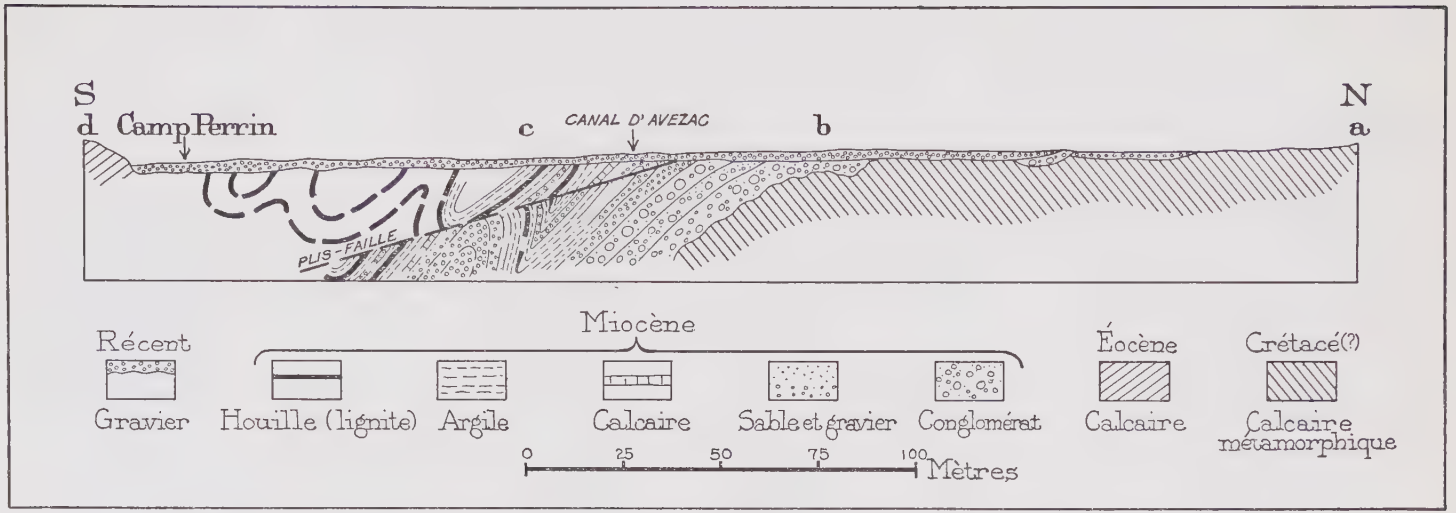


FIGURE 17.—Section of Miocene lignite-bearing beds exposed north of Camp Perrin on La Ravine du Sud.

See fig. 16 for line of section *a*—*b*—*c*—*d*. Structure below the surface beds from *a* to *c* is largely hypothetical.

Section of nonmarine Miocene beds on La Ravine du Sud.

No. of bed.	Kind of bed.	Strike and dip.	Approximate thickness (meters).
44	Clay, poorly exposed	.....	35
43	Green clay	N. 60° E.; 45° SE.	5
42	Interbedded shale and lignite	.....	1
41	Gravel	.....	1
40	Shale containing a poorly exposed bed of lignite.	.....	7
39	Shale and lignite	.....	0.6
38	Shale	.....	2
37	Good hard lignite	.....	0.3
36	Thin-bedded hard shale	.....	2
35	Gravel	East-west; 75° S...	2
34	Shaly limestone	.....	5
33	Good hard lignite; sample 1	.....	0.9
32	Shale with lignite	.....	1
31	Thin-bedded limestone	.....	0.5
30	Green clay	.....	9
29	Coarse gravel, pebbles, 2 to 3 cm. in diameter...	.....	1
28	Green clay	N. 70° W.; 75° SW.	9
27	Sandy clay with shells and fossil wood; station 9624	.....	0.5
26	Green clay	.....	32
25	Blue marl and shale	.....	4
24	Shaly limestone	.....	0.7
23	Lignite and clay	.....	0.8
22	Blue marl	.....	3
21	Hard lignite	.....	0.5
20	Dark-green clay	N. 70° E.; 40° SE.	2
19	Shale grading into lignite	.....	1
18	Green and red clay	.....	2
17	Thin-bedded shaly limestone	.....	1.5
16	Clay and thin seams of lignite	.....	2
15	Hard lignite poorly exposed	.....	0.7
14	Chiefly clay, some limestone	.....	7
13	Limestone	.....	0.7
12	Blue marl, containing fossil wood at base	East-west; 45° S...	7
11	Impure limestone	.....	2
10	Blue marl and green clay	.....	28
9	Coarse gravel with fossil wood	.....	2
8	Green clay with thin beds of calcareous sandstone	.....	9
7	Shaly limestone carrying thin seams of lignite...	.....	0.3
6	Clay	N. 70° E.; 40° SE.	2
5	Gravel	.....	1
4	Chiefly green clay, some gravel	.....	30
	Diversion dam, Canal D'Avezac	.....	
3	Principally sandy clay. In lower part of section some gravel; in upper part some limestone and traces of carbonaceous shale; in midde of section fossil wood. Station 9640 about 15 meters above base; station 9625 about 20 meters from top	N. 55° E.; 50° SE.	64
2	Coarse gravel, some pebbles 10 cm. diameter	.....	3
	Total thickness of beds exposed upstream from this locality	.....	289
2	Coarse gravel, same bed as No. 2	N. 55° E.; 60° NW.	3
3	Sandy clay, etc., same bed that overlies No. 2....	.....	25
	Fault; about 30 meters concealed	.....	
1	At base very coarse and poorly stratified conglomerate with some boulders more than a meter in diameter, resting unconformably on metamorphosed limestone. Grades into finer and better stratified material above. Lenticular beds of gravel and sand near top	N. 45° E.; 30° SE.	200

The estimated thickness of the beds in the unbroken southward or southeastward dipping section above the fault on La Ravine du Sud is 289 meters. As neither the top nor the base of the section is exposed, the total thickness of this lignite-bearing section exceeds 300 meters. The apparent thickness of the coarse basal conglomerate to the north of the fault is about 200 meters, but a part of it may possibly correspond to certain beds in the lignite-bearing section to the south. The Miocene beds probably have a total thickness of about 500 meters.

The structure of the beds, as can readily be seen from the strikes and dips in Figure 16, is very complicated. The whole lignite-bearing part of the section appears to be crumpled into close folds, which are very likely overturned to the north. The general strike of the beds is east and west, parallel to the length of the lowland, but locally the strikes are divergent.

The northward strikes found along a ravine in the section examined on La Rivière probably indicate faulting, although more work would be required to determine the structure in that locality. In the section on La Ravine du Sud there seems to be clear evidence of an extensive fault at the contact of the conglomerate and the lignite-bearing beds. As the anticlinal fold south of the contact is slightly overturned to the north and as the beds of conglomerate plunge with uninterrupted dip beneath this fold, the contact is interpreted as a thrust fault. (See Fig. 17.)

Positive correlation of the coarse unfossiliferous conglomerate with the finer fossiliferous, lignite-bearing beds to the south is impossible, but as the finer beds in the conglomerate closely resemble the coarse gravel beds in the other part of the section and as the degrees of consolidation and deformation are comparable, they probably belong to the same series. If this assumption is true the conglomerate represents a basal and marginal phase of the series, and certain beds in the lignite-bearing series may possibly be the equivalent of some of the finer beds in the conglomerate, as shown in Figure 17.

When the Miocene beds were deposited there was a land mass on the north which supplied sediment to a lowland, probably a plain, on the south. Near the border of this lowland the sediment was coarse and was probably deposited on land. Farther south the sediment became progressively finer, and some of it was deposited in fresh-water swamps, forming beds of clay, limestone, and lignite. A similar change in the character of the sediments can be observed at the present time on the Cayes Plain, where coarse gravel at the northern border of the plain grades into clay and even into peaty material in the swampy land near the sea. Still farther south, beneath Cayes Bay, there are marine beds. The beds of lignite and marl at Camp Perrin may grade into marine beds farther south, as Miocene marine beds are exposed in hills on the Cayes Plain.

The low mountain range south of the dissected lowland has been elevated since the Miocene beds were deposited. The upper Eocene limestone may have been thrust northward over the Miocene beds in the same manner in which the lignite-bearing beds appear to have been thrust northward over the basal and marginal conglomerate.

Evidence of several kinds indicate that the lignite-bearing beds are of Miocene age, although the fresh-water and land mollusks, lignified stems, and large pieces of wood that were collected from them do not positively establish their age. The beds are lithologically and structurally similar to the Miocene beds in similar dissected lowlands of the Southern Peninsula. Moreover, they are probably the equivalent of the marine Miocene beds that crop out on the Cayes Plain and at one time may have been continuous with those beds before the ridge of upper Eocene limestone was elevated and the Miocene beds removed from it by erosion.

Fossils.—An interesting fauna of land and fresh-water mollusks was obtained from the lignite-bearing beds at Camp Perrin. The land mollusks were examined by the late Mr. John B. Henderson, of the United States National Museum. Although most of the specimens are crushed it seems that the genera *Thysanophora* and *Crocidopoma* are represented. These two genera have not heretofore been found in beds as old as Miocene. *Pachycheilus* is rather abundant at station 9624. The molluscan faunas of the nonmarine beds in the Asile Valley and at Camp Perrin are entirely different, although they seem to be of about the same age.

Stations near Camp Perrin (nonmarine Miocene).

9624 (B 57 F). Arrondissement of Cayes, la Ravine du Sud, about 300 meters below intake of Canal d'Avezac. J. S. Brown, collector. November 5, 1920.

9625 (B 60 F). Arrondissement of Cayes, la Ravine du Sud, about 150 meters below intake of Canal d'Avezac. J. S. Brown, collector. November 6, 1920.

9640 (B 61 F). Arrondissement of Cayes, la Ravine du Sud, just above intake of Canal d'Avezac. J. S. Brown, collector. November 6, 1920.

Nonmarine Miocene fossils from Camp Perrin.

Species.	9624	9625	9640
Mollusca:			
Gastropoda:			
Thysanophora sp.	....	×	....
Crocidopoma sp.	....	×	....
Pachycheilus sp.	×	....	×
Hydrobia	....	....	×
Pelecypoda:			
Cyrena ? sp.	....	....	×

Cayes Plain.

A considerable number of low rounded hills rise from 10 to 30 meters above the alluvial deposits in the northern and northwestern parts of the Cayes Plain. These hills were examined at only one locality along one of the main trails between Les Cayes and Camp Perrin, about 18 kilometers up the trail northwest of Les Cayes and 3 kilometers southeast of a habitation called La Vie, which is at the border of the plain. The locality is only a few hundred meters east of La Ravine du Sud. The trail passes between two hills which form part of a low chain that trends northwestward.

The rocks exposed along the trail and in an adjacent ravine consist principally of soft limestone and a little interbedded clayey marl. The beds are approximately horizontal. The limestone contains poorly preserved corals and mollusks. (See list below; station 9626.)

Similar marine Miocene beds probably form the other hills, and Miocene beds very likely underlie all or most of the Cayes Plain, the hills being either erosional remnants not covered by alluvium or eminences formed by uplift, either through folding or faulting. The suggestion also seems warranted that these marine beds are the seaward equivalent of the nonmarine lignite-bearing Miocene at Camp Perrin.

Fossils.—Only two fossils, one coral and one mollusk, were collected from the limestone in the Cayes Plain, but the coral is similar to a Miocene species from Cuba.

Station in Cayes Plain (Miocene).

9626 (B 63 F). Arrondissement of Cayes, main trail from Les Cayes to Camp Perrin, about 3 kilometers southeast of habitation La Vie. J. S. Brown, collector. November 7, 1920.

Miocene fossils from station 9626, Cayes Plain.

Coral:
Goniopora sp. cf. G. jacobiana Vaughan.

Mollusca:
Lithophaga sp.

Gonave Island.

Rocks of known or supposed Miocene age cover a large part of Gonave Island, but as they consist entirely of limestone it is difficult to distinguish them from the older rocks, which also are limestone. The Miocene limestone is massive, white on unweathered surfaces, and usually gray on weathered surfaces except beneath overhanging cliffs and in other sheltered places, where it weathers yellowish. Although no accurate estimate of its thickness is possible the Miocene is probably less than 200 meters thick. It rests with transgressive overlap on the upper Eocene limestone, at some places on the upper massive beds and at others on the lower chalky beds. Where it rests on the massive upper Eocene limestone

it is almost impossible to distinguish them unless fossils are found. The supposed stratigraphic relations of the Miocene limestone is shown in Figure 8, page 138.

The Miocene limestone forms a fringe around the north and south coasts of the southeastern half of the island. South of Anse-à-Galets, on the north coast, it crops out on a steep slope leading up to a dissected coastal plateau. The rock there is jagged and deeply pitted by solution cavities. The corals listed on page 239, station 9661, were collected near the top of the slope a short distance east of the trail leading southwestward from Anse-à-Galets to the spring that supplies the village. This trail follows the channel of a ravine along which the Miocene limestone crops out at intervals. About 2 kilometers southwest of Anse-à-Galets the limestone is exposed in a cliff about 50 meters high, on the east side of the ravine. Corals and mollusks were collected in a shallow cavern at the foot of this cliff. (See list, p. 239, station 9663.) In the cavern the rock weathers to a soft powdery marl containing hard lumps of yellowish limestone, but on the outside of the cliff it is gray and jagged. Near this place calcareous rind on the surface of the limestone contains specimens of the Recent land snails *Urocoptis* (*Autocoptis*) *gruneri* Dunker and *Pleurodonte*. Another collection of corals was obtained along the trail leading from Anse-à-Galets northwestward along the coast to Étroit, at a point about 4 kilometers from Anse-à-Galets, where the massive pitted limestone extends to the shore line. (See list, p. 239, station 9680.)

The surface rock over the entire northwestern half of the island consists of similar massive limestone etched into fantastic shapes by solution. It is supposed to be of Miocene age, but the only fossils obtained are the impressions of the few mollusks listed on page 239, stations 9675, 9677, and 9678. Erosion remnants of this limestone resembling ruined walls rest on the chalky upper Eocene limestone about a kilometer south of Fond-Negre on the trail to Grande Ravine. On the same trail, about 3 kilometers northwest of Grande Ravine and near the foot of the slope leading up to the interior plateau, massive limestone of supposed Miocene age rests on an uneven surface of the chalky upper Eocene limestone that underlies the plateau.

Fossils.—The corals collected from the limestone on Gonave Island have a Miocene aspect, and some of them are similar to species obtained from Miocene beds on the mainland. The mollusks have no stratigraphic significance.

Stations on Gonave Island (Miocene).

9661 (W 153 F). Gonave Island, short distance east of trail leading southwestward from Anse-à-Galets, about a kilometer southwest of Anse-à-Galets; altitude 60 meters above sea level. W. P. Woodring, collector. December 17, 1920.

9663 (W 155 F). Gonave Island, trail leading southwestward from Anse-à-Galets, cliff on right side of dry ravine about 2 kilometers from Anse-à-Galets. W. P. Woodring, collector. December 17, 1920.

9680 (W 175 F). Gonave Island, trail from Étroit to Anse-à-Galets, about 4 kilometers northwest of Anse-à-Galets. W. P. Woodring, collector. December 25, 1920.

9675 (W 169 F). Gonave Island, trail from Grande-Ravine to Fond-Negre, about 5 kilometers northwest of Grande Ravine; altitude 410 meters above sea level. W. P. Woodring, collector. December 22, 1920.

9677 (W 171 F). Gonave Island, trail from Fond-Negre to Dandeville, about 8 kilometers west-northwest of Fond-Negre; altitude 190 meters above sea level. W. P. Woodring, collector. December 23, 1920.

9678 (W 172 F). Gonave Island, trail from Fond-Negre to Dandeville, about 15 kilometers west-northwest of Fond-Negre; altitude 275 meters above sea level. W. P. Woodring, collector. December 23, 1920.

Miocene fossils from Gonave Island.

Species.	9661	9663	9680	9675	9677	9678
Corals:						
Stylophora sp.	×	×	....	....	....	....
Stephanocoenia intersepta (Esper)	....	....	×	....	....	....
Meandrina sp. apparently new	....	×	....	....	....	....
Orbicella sp. cf. O. altissima (Duncan)	....	×	....	....	....	....
Mollusca:						
Gastropoda:						
Conus sp.	....	×	....	....	....	....
Xancus ? sp.	....	×	....	....	....	....
Cerithium sp.	....	....	....	....	×	....
Emarginula ? sp.	....	....	....	....	....	×
Pelecypoda:						
Chlamys (Aequipecten) sp.	....	....	....	×	....	....
Lucina ? sp.	....	×	....	....	....	....

Pliocene Series.

Faunal evidence and the degree of deformation of the rocks are the criteria used in recognizing marine deposits of Pliocene age in Haiti. Judged by these criteria marine Pliocene deposits appear to be confined to relatively small areas in the Southern Peninsula. Some of the coralliferous limestones and other marine beds called Quaternary may really be Pliocene, but all the beds classed as Quaternary are undeformed or only slightly deformed and have approximately the same fauna. Nonmarine deposits of Pliocene age are known in some of the larger valleys and plains. They are more dissected than similar Quaternary beds and may consist of different material.

MARINE DEPOSITS.

Valley of Rivière Gauche.

The lowland that is drained by Rivière Gauche, extending northwestward from Jacmel for at least 17 kilometers, contains marine deposits of Pliocene age. On the northeast side of the lowland these beds rest unconformably on upper Eocene limestone, although at some localities they

have about the same strike and dip as the upper Eocene rocks. The relation to the older rocks along the foot of the steep, cliff-broken slope on the southwest side of the lowland are not known. The Pliocene beds are folded, and along the trail following Rivière Gauche they dip steeply southwestward. They consist principally of conglomerate and marl. The conglomerate is firmly consolidated, except certain very coarse beds, and contains pebbles and cobbles of different kinds of limestone, which have a maximum diameter of half a meter. It contains also cobbles of chert and basalt, which, however, are much less numerous. At some places the conglomerate is made up of pebbles of uniform size, 5 or 6 centimeters in diameter. Interbedded with the conglomerate are beds of gray and yellow marl containing sandy and clayey layers. Some of the beds of marl carry perfectly preserved fossils. Fossils were collected from thin marl beds at two localities. (See list, p. 242, stations 9529 and 9530.) There are also a few beds of limestone containing poorly preserved corals and mollusks.

The strike of the beds along Rivière Gauche below Boucicaut is parallel to the longer diameter of the lowland and the dip is southwestward at angles of 40° to 50°. The thickness of these beds is not known but is probably more than 100 meters.

Near the mouth of Rivière Gauche and on Rivière Gosseline, at the southeast end of the lowland, the Pliocene beds dip more gently southwestward at angles of 10° to 25°, having virtually the same strike and dip as the underlying upper Eocene limestone. A bluff on the right bank of Rivière Gosseline exposes marly sandstone and sandy marl containing casts of the mollusks listed on page 242, station 9604.

Tapion du Petit-Goave.

The beds in the gap south of Tapion du Petit-Goave seem to consist chiefly of the Miocene rocks that are described on page 224. Along the road on the west slope a thick coralliferous limestone overlies the Miocene rocks. It is more massive than the coralliferous limestones interbedded with the Miocene conglomerate but seems to have about the same dip. An extensive series of corals (see list, p. 243, station 9793) collected along the road at an altitude of 150 meters above sea level contains only genera still living in the West Indies, and this limestone is believed to be either Pliocene or Quaternary—probably Pliocene, because the beds are more greatly deformed than those classed as Quaternary.

NONMARINE DEPOSITS.

Nonmarine deposits of Pliocene age probably underlie similar Quaternary deposits in most of the larger valleys and plains, but detailed work would be required to separate them. Most of the dissected nonmarine deposits in these regions are arbitrarily called Quaternary.

Central Plain.

Hinche formation.

In the Central Plain beds of silt, clay, sand, and gravel, usually unconsolidated or imperfectly consolidated, rest on the eroded surface of the folded rocks of the Artibonite group. These beds were apparently laid down along a drainage system that emptied southeastward into the San Juan Valley of the Dominican Republic. Jones[1] gave the name "Hinche beds," derived from the town of Hinche, to these stream deposits. So far as observed these rocks are undeformed. They closely resemble imperfectly consolidated rocks of similar origin in the Las Cahobas formation, and where the Las Cahobas rocks lie flat, as in the trough of the Central Plain syncline, the two formations can hardly be distinguished. The gravels of the Hinche beds contain a greater proportion of limestone pebbles than is found in poorly consolidated conglomerates in the upper part of the Las Cahobas formation, but they do not contain the large boulders of limestone and brown chert that are common in the Quaternary stream gravels. The Hinche beds underlie the extensive savanna in the northwestern part of the plain and patches of them are found at successively lower altitudes in the southeastern part. The estimated maximum thickness of this formation is 25 meters.

The Hinche formation is considered Pliocene because of its stratigraphic position. It is the equivalent of the Las Matas formation of the San Juan Valley in the Dominican Republic, and the two formations are probably continuous.

FOSSILS.

The corals obtained from the Pliocene beds on Rivière Gauche have a more modern aspect than the Miocene corals collected in the Republic. Only five genera are represented, but these genera are all still living in the West Indian region. *Maeandra labyrinthiformis* (Linnaeus) and *Acropora muricata* (Linnaeus) have never been recorded from West Indian Miocene deposits.

The molluscan fauna seems to be intermediate between Miocene and Quaternary faunas. Species like *Fusinus* sp. cf. *F. ulcimus rushii* Dall, *Astrea* sp. cf. *A. caelata* Gmelin, *Calliostoma* sp. cf. *C. zonamesta* Reeve, and *Torinia* sp. cf. *T. cylindrica* (Gmelin) are more modern than any Miocene species. The *Sconsia* is intermediate between the Miocene *S. laevigata* (Sowerby) and the Recent *S. striata* (Lamarck). *Torinia rotundata* Gabb, recently figured by Pilsbry,[2] is the only *Torinia* recorded from West Indian Miocene deposits, although a similar species is listed on page 225, station 9481, from the Miocene at the west end of the Léogane

[1] Jones, W. F., A geological reconnaissance in Haiti; a contribution to Antillean geology: Jour. Geology, vol. 26, p. 748, 1918.

[2] Pilsbry, H. A., Revision of W. M. Gabb's Tertiary Mollusca of Santo Domingo: Acad. Nat. Sci. Philadelphia Proc., vol. 73, p. 379, pl. 34, figs. 19-20, 1922.

Plain. The species from the Pliocene beds is more similar to the Recent *T. cylindrica* (Gmelin). Other mollusks from these beds resemble Bowden and Gurabo (Miocene) species.

Marine deposits of Pliocene age have not been recognized in other West Indian islands, with the doubtful exception of Cuba, but beds of this age are known at Port Limon, Costa Rica.

Most of the corals from the limestone on the west slope of Tapion du Petit-Goave are Recent species, but the limestone is considered of doubtful Pliocene age because of its structural relations.

Stations in arrondissement of Jacmel (Pliocene).

9529 (K 30 F). Arrondissement of Jacmel, trail from Jacmel to Boucicaut, right bank of Rivière Gauche, about 7 kilometers northwest of Jacmel. W. S. Burbank, collector. November 16, 1920.

9530 (K 31 F). Arrondissement of Jacmel, trail from Jacmel to Boucicaut, left bank of Rivière Gauche, about 9 kilometers northwest of Jacmel. W. S. Burbank, collector. November 16, 1920.

9604 (W 68 F). Arrondissement of Jacmel, trail from Jacmel to Carrefour, right bank of Rivière Gosseline 100 meters above second crossing above Jacmel. W. P. Woodring, collector. November 3, 1920.

Pliocene fossils from beds on Rivière Gauche, arrondissement of Jacmel.

Species.	9529	9530	9604
Corals:			
Solenastrea hyades (Dana)	×	....	....
Maeandra labyrinthiformis (Linnaeus)	×	....	....
Maeandra ? sp.	×	....	....
Siderastrea sp. aff. S. siderea (Ellis and Solander)	×	....	....
Agaricia sp.	×	....	....
Acropora muricata (Linnaeus)	....	×	....
Mollusca:			
Pteropoda:			
Cavolina sp. cf. C. tridentata Forskal	....	....	×
Gastropoda:			
Oliva sp. cf. O. reticularis Lamarck	....	×	....
Olivella sp. cf. O. jaspidea rotunda Dall	....	×	....
Fusinus sp. cf. F. ulcimus rushii Dall	....	×	....
Phos sp. cf. P. moorei Guppy	....	×	....
Murex sp. cf. M. domingensis Sowerby	....	×	....
Sconsia sp. cf. S. laevigata (Sowerby)	....	×	?
Colubraria sp.	....	×	....
Turritella sp. cf. T. submortoni Maury	....	×	....
Astrea sp. cf. A. caelata (Gmelin)	....	×	....
Calliostoma sp. cf. C. zonamesta Reeve	....	×	....
Torinia sp. cf. T. cylindrica (Gmelin)	....	×	....
Pelecypoda:			
Leda sp.	....	....	×
Glycymeris sp. cf. G. pennacea (Lamarck)	....	×	....
Chlamys (Aequipecten) sp. cf. C. (A.) uselmae Pilsbry and Johnson.	....	×	....
Cardium (Fragum) medium Linnaeus	....	×	....

Stations on west slope of Tapion du Petit-Goave (Pliocene ?).

9793 (W 317 F). Arrondissement of Léogane, road from Léogane to Miragoâne, west slope of Tapion du Petit-Goave, altitude 150 meters above sea level. T. W. Vaughan and W. P. Woodring, collectors. March 6, 1921.

9470 (B 33 F). Arrondissement of Léogane, road from Léogane to Miragoâne, west slope of Tapion du Petit-Goave, altitude about 100 meters above sea level. J. S. Brown, collector. October 23, 1920.

Pliocene (?) fossils from west slope of Tapion du Petit-Goave.

Species.	9793	9470
Corals:		
Orbicella annularis (Ellis and Solander)	×	....
Solenastrea bournoni Milne-Edwards and Haime	×	....
Solenastrea hyades (Dana)	×	....
Maeandra labyrinthiformis (Linnaeus)	×	....
Siderastrea sp. aff. S. sidera (Ellis and Solander)	×	....
Agaricia agaricites var. purpurea (Le Sueur)	×	....
Porites sp. cf. P. porites (Pallas)	×	....
Porites sp. cf. P. astreoides Lamarck	×	....
Mollusca:		
Gastropoda:		
Bullaria ? sp.	....	×
Pelecypoda:		
Arca umbonata Lamarck	....	×
Chlamys (Aequipecten) sp. cf. C. (A.) phrygium Dall	×	×
Chlamys (Plagioctenium) sp. cf. C. (P.) gibbus Lamarck	....	×
Ostrea sp.	×	....
Venus campechiensis Gmelin ?	×	....
Chione ? sp.	×	×
Macrocallista ? sp.	×	....

QUATERNARY SYSTEM.

General Features.

The effects of the rise and decline of glaciation in the temperate regions are apparently not recognizable in the Republic, either directly or indirectly, and the limits of Pliocene, Pleistocene, and Recent time are poorly defined, depending on several criteria, none of which can be rigidly applied. Deposits that are poorly consolidated, that are undeformed or only slightly deformed, that are dissected by present streams, and that contain a fauna identical with or very similar to the living fauna are here considered Quaternary.

Quaternary sedimentary deposits are rather widely distributed in the Republic, although most of the areas in which they form the surface rocks are small. (See Pl. I.) They may be divided into marine and nonmarine deposits.

Marine Deposits.

Marine Quaternary deposits are common only along the coast, where they form narrow fringes, at few places more than 1 or 2 kilometers wide.

However, they spread over virtually all the Bombardopolis Plateau, thus extending back many kilometers from the coast. Small patches are found along the north and south borders of the Cul-de-Sac Plain to and beyond the international boundary. This probably is the greatest distance inland at which marine Quaternary deposits have been found, but when they were deposited the sea occupied the trough now known as the Cul-de-Sac Plain, and these deposits, like the others, are therefore coastal fringes. These marine Quaternary deposits cover the emerged coastal terraces that stretch along nearly one-half the coast of the Republic.

STRATIGRAPHIC RELATIONS.

The Quaternary deposits everywhere rest on the underlying formations unconformably. The unconformity is angular as well as erosional, even with the Pliocene and Miocene, but at some places where there are no Pliocene deposits the discordance with the Miocene deposits may be slight.

LITHOLOGY AND LOCAL DETAILS.

The greater part of the marine Quaternary deposits are reef deposits very similar to those now forming at many localities around the shore of the Republic. They consist of reef rock, coralliferous limestone, and molluscan limestone, but reef rock and coralliferous limestone are the most common, a fact indicating that fringing reefs were flourishing during probably all of Quaternary time. If some of these rocks are indeed of Pleistocene age, as seems probable, there seems to be no basis, at least so far as the Republic of Haiti is concerned, for the contention that the vigorous growth of Pleistocene reefs was retarded by the supposed lowering of the temperature of tropical seas during Pleistocene time. Although detailed work should be done to warrant definite statements, it seems that the maxima of Pleistocene glaciation can not be recognized by their effect on the Pleistocene reefs. The reefs of supposed Pleistocene age are similar in many features to the Recent reefs. The list on page 250 shows that *Orbicella annularis* (Ellis and Solander) was the most common reef builder in the emerged Quaternary deposits, just as it is the most common coral on the living West Indian reefs.

At few places does the weathered surface of the limestone give a correct impression of its lithology, which can be observed only in very fresh stream-cut bluffs or in artificial excavations. In such favorable exposures the rock is seen to consist of thick-bedded, poorly assorted, and very poorly consolidated calcareous and detrital materials, in most places containing a large proportion of heads of corals and shells of mollusks. There are all gradations of rock from pure coral and pure coquina to gravel derived entirely from land débris. Ordinarily the purer calcareous rock is found near the sea or on the outer margins of terraces, and the detrital material is found at the landward margin of the deposits. The charac-

teristic gradation is well shown along the Rivière des Roseaux near Roseaux, a village about 7 kilometers east of Jérémie. The terrace near the shore is composed very largely of heads of corals and shells of mollusks. To the south the organic remains become rarer and rarer, and the detrital materials become more and more abundant, until in the bluffs about a kilometer south of Roseaux only dissected water-laid gravels can be found. The zone of gradation ordinarily, however, is not conspicuous. At some places where the initial slope was steep a narrow reef is plastered almost directly on the basement of the older rocks. This relation is shown at St.-Marc Bay, where relatively wide terraces veneered with reef rock or coralliferous limestone cover the promontories north and south of the bay. At the head of the bay, just south of the place where the road to Gonaïves leaves the coast and enters the ravine, a narrow fringe of coralliferous limestone rises to an altitude of 15 meters above sea level. The limestone grades laterally and vertically into marl and poorly consolidated gravels. The fossils listed on pages 250-254 (station 9551) were collected here. At some places the zone of gradation is obscured by later alluvial deposits or is indistinguishable from them. In places it seems that the deposits in the zone of gradation are softer than the more calcareous rock and have been eroded away, as at the rear of the coastal escarpments near Anse Rouge and north of Jean Rabel. The erosion in both these localities, however, has undoubtedly been due primarily to the presence of soft Miocene beds back of the Quaternary limestone.

A lateral gradation in constituent material somewhat like that just described was observed at some places directly on the shore, where the prevailing coralliferous limestone of the lowest coastal terraces is replaced for an interval by stratified gravel or sand that generally contains marine fossils in considerable numbers. This type of material doubtless represents the delta deposits of streams which at their mouths interrupted the continuity of the reefs by depositing a large amount of sediment. Such a gradation is particularly well shown just west of the mouth of Rivière de Jean Rabel, along the trail between Môle St.-Nicolas and Jean Rabel. The coralliferous limestone typically developed 2 or 3 kilometers west of that stream grades eastward into stratified sand and coarse gravel containing few fossils, such as that found in bluffs along the Rivière de Jean Rabel. Again, between Petit-Rivière de Nippes and Grande-Rivière de Nippes the prevailing coralliferous limestone is replaced by fine-grained soft brown sand containing shells of mollusks. (See list, pp. 250-254; station 9520.) At these two localities, as probably at most others, the main streams of Quaternary time seem to have occupied approximately the same valleys which they now occupy, and Quaternary delta deposits may normally be expected at the mouths of all the larger streams where the coast has emerged during Quaternary time.

Where they have been long exposed to weathering the Quaternary rocks assume an appearance very different from that which they show in fresh

excavations. The fossils are commonly dissolved by preferential leaching, leaving the surface of the rock pitted, and only casts or impressions of the fossils remain. A veneer of travertine deposited over the rock surface in many places accentuates its massive appearance. There is also a pronounced hardening of the outer crust, which commonly extends to a depth of several meters. This hardening is probably due mainly to firm cementation of the particles by redeposited calcium carbonate. The density of the rock also may be increased to some extent by this introduced material, some of which was probably brought to the surface by capillary water, which having penetrated the rock to a shallow depth returned to the surface and evaporated, leaving its dissolved material behind. As a result of these changes the purer calcareous Quaternary rock may closely resemble phases of the massive upper Eocene and other Tertiary limestones, as for instance, in the cliff shown in Plate XVII, *A*. Some of the Quaternary limestone also yields a red clay soil almost identical with that characteristic of areas of the massive Tertiary limestones.

The following section of Quaternary deposits is exposed in a sea cliff 7 meters high just west of the colonial fort on the west side of the entrance to the harbor of Port-de-Paix:

Section of Quaternary beds exposed near Port-de-Paix.

	Meters.
Reef rock, yellowish buff, soft, containing large heads of *Orbicella annularis* and other corals; station 9765	3.6
Waterworn pebbles, poorly consolidated, in matrix of sand; lenses of sand containing worn shells and small pieces of corals; station 9764	1.5
Sand, rusty brown, poorly consolidated, fragmentary shells in pockets	2
Sea level.	
	7.1

The lenses of sand in the middle bed furnished the largest collection of Quaternary mollusks obtained in the Republic. (See list, pp. 250-254, station 9764.) The overlying reef rock contained only a few mollusks.

The remarkable emerged coastal terraces of the Northwest Peninsula are described on pages 371-375, and the fossils obtained from the coralliferous limestone covering them are listed on pages 250-254 (stations 9841, 9840, 9844, 9838, 9837, 9836, 9835, 9834, 9833, 9832, and 9831).

In the Cul-de-Sac Plain the most extensive areas of Quaternary limestone lie along the south side. The best collection of corals was obtained at Balan, near the southwest corner of Étang Saumâtre. (See list, p. 250; station 9659.) Along the trail from Gantier to Fond-Parisien cavernous limestone crops out near Pont Quinet at an altitude of about 150 meters above sea level. This limestone is the surface rock for most of the distance from this locality eastward to Fond-Parisien and probably forms the ridge that extends northward to the lake. Partly dissolved corals were collected about 3 kilometers northwest of Fond-Parisien at an altitude of 90 meters above sea level. (See list, p. 250; station 9591.)

A. PITTED QUATERNARY LIMESTONE (ROCHE-À-RAVET) EXPOSED IN FIFTH EMERGED SEA CLIFF ON THE TRAIL FROM PETIT PARADIS TO BAIE DE HENNE.

B. PLEISTOCENE CONGLOMERATE ON THE ROAD LEADING UP TO FORT NATIONAL, PORT-AU-PRINCE.

Note the hardened surface crust.

At numerous other localities where Quaternary deposits fringe the coast they consist of one of the types of deposits that have just been described. The terraces on which they rest are fully described in Part III.

THICKNESS.

Because of the great unevenness of the floor on which it was deposited and the unequal amount of erosion at the surface the thickness of the marine Quaternary is decidedly variable. It probably exceeds 50 meters at but few places, although on the Bombardopolis Plateau the maximum thickness may be 100 meters. At La Gorge, on Rivière du Môle, southeast of Môle St.-Nicolas, the contact of the Quaternary deposits with the underlying Miocene beds is at an altitude of less than 100 meters above sea level, and the Quaternary deposits rise to heights of about 400 meters above sea level on the plateau on either side of the river valley. It can not be assumed, however, that the intervening interval represents the thickness of the Quaternary, because on each of the terraces the Quaternary is represented only by a thin lens of deposits that gradually tapers landward and more rapidly seaward.

STRUCTURE.

The structure of the Quaternary formations is very simple. Although they have undergone arching, as indicated by the unequal amounts of emergence of the coastal terraces, especially in the Northwest Peninsula, they are not at all crumpled, as are the underlying formations. At most places they were deposited with a pronounced seaward dip, commonly from 5° to 15°, which is generally visible in large excavations or in deep stream channels. As the direction of the coast line changes the direction of dip determined by the initial slope usually changes correspondingly.

FOSSILS.

Some of the collections here classified as Quaternary may really be Pliocene. It is very difficult to distinguish Pleistocene from Pliocene faunas, a difficulty which probably accounts for the apparent scarcity of Pliocene deposits in the American tropics. No adequate attempt has yet been made in the American tropics to separate Pleistocene and Recent faunas, much less to recognize faunal zones in the Pleistocene.

Corals are the most abundant marine Quaternary fossils, as the most common rock is coral reef rock or coralliferous limestone. Virtually all the species are identical with living ones. *Orbicella annularis* (Ellis and Solander) was obtained at almost every locality where collections were made from rocks of this type. *Solenastrea bournoni* Milne-Edwards and Haime, *Siderastrea siderea* (Ellis and Solander), and *Acropora muricata* (Linnaeus) are other common Quaternary corals. The lists of Miocene corals (see pp. 178, 203, 217) show that the following Recent species were living in Miocene time: *Orbicella annularis, Dichocoenia stokesi, Stephanocoenia intersepta, Solenastrea bournoni, Solenastrea hyades,* and *Siderastrea siderea.* A small collection of Miocene corals may therefore

resemble a Quaternary fauna, unless it includes *Stylophora, Pocillopora, Antillia, Cyathomorpha, or Goniopora.*[1]

The molluscan fauna of the Quaternary fringing reefs is rather meager, but the total molluscan fauna is extensive, because large collections were obtained at localities where the deposits consist of sand and gravel or of limestone that contains hardly any corals. *Strombus gigas* Linnaeus, *Arca umbonata* Lamarck, *Codakia orbicularis* (Linnaeus), and *Phacoides pennsylvanicus* (Linnaeus) are the common mollusks of the fringing reefs. Not enough time was given to the determination of the mollusks to show clearly whether any of them are different from living West Indian species. Most of those that are not determined specifically are poorly preserved.

Stations in marine Quaternary deposits.

9764 (W 301a F). Arrondissement of Port-de-Paix, on the coast, 100 meters west of old fort on west side of entrance to Port-de-Paix harbor; from middle bed of section on page 246. W. P. Woodring, collector. February 21, 1921.

9765 (W 301b F). Arrondissement of Port-de-Paix, same locality as 9764; from upper bed of section on page 246. W. P. Woodring, collector. February 21, 1921.

9841 (B 210 F). Arrondissement of Môle St.-Nicolas, trail from Môle St.-Nicolas to Jean Rabel, about 2 kilometers northeast of Môle St.-Nicolas. J. S. Brown, collector. January 30, 1921.

9840 (B 209 F). Arrondissement of Môle-St.-Nicolas, cliff at northeast end of bay. J. S. Brown, collector. January 30, 1921.

9844 (B 211a F). Arrondissement of Môle St.-Nicolas, trail from Môle St.-Nicolas to Bombardopolis, about 2 kilometers south of Môle St.-Nicolas. J. S. Brown, collector. January 31, 1921.

9838 (B 207 F). Arrondissement of Môle St.-Nicolas, trail from Môle-St.-Nicolas to Bombardopolis, about 8 kilometers northwest of Bombardopolis. J. S. Brown, collector. January 29, 1921.

9837 (B 206 F). Arrondissement of Môle St.-Nicolas, trail, from Môle St.-Nicolas to Bombardopolis, about halfway between the towns. J. S. Brown, collector. January 29, 1921.

9836 (B 205 F). Arrondissement of Môle St.-Nicolas, trail from Môle St.-Nicolas to Bombardopolis, about 7 kilometers northwest of Bombardopolis. J. S. Brown, collector. January 29, 1921.

9835 (B 204 F). Arrondissement of Môle St.-Nicolas, trail from Môle St.-Nicolas to Bombardopolis, about 5 kilometers northwest of Bombardopolis. J. S. Brown, collector. January 29, 1921.

9834 (B 203 F). Arrondissement of Môle St.-Nicolas, trail from Môle St.-Nicolas to Bombardopolis, about a kilometer northwest of Bombardopolis. J. S. Brown, collector. January 29, 1921.

9833 (B 200 F). Arrondissement of Môle St.-Nicolas, trail from Bombardopolis to Baie de Henne, about 3 kilometers west of Baie de Henne and halfway up slope of Morne Chien. J. S. Brown, collector. January 27, 1921.

9832 (B 199 F). Arrondissement of Môle St.-Nicolas, trail from Bombardopolis to Baie de Henne, 2 kilometers west of Baie de Henne, foot of Morne Chien. J. S. Brown, collector. January 27, 1921.

9831 (B 197 F). Arrondissement of Gonaïves, trail from Terre-Neuve to Anse Rouge, gap in low range of coastal hills about 5 kilometers southeast of Anse Rouge. J. S. Brown, collector. January 25, 1921.

[1] There are other West Indian Miocene genera now confined to the Indo-Pacific region, or extinct. (See Vaughan, T. W., U. S. Nat. Mus. Bull. 103, p. 222, 1919.) The genera listed are known in the Miocene fauna from the Republic of Haiti.

9551 (W 2 F). Arrondissement of St.-Marc, road from St.-Marc to Gonaïves, steep slope on east side of road at outskirts of St.-Marc. W. P. Woodring, collector. September 29, 1920.

9479 (B 120 F). Arrondissement of St.-Marc, road from St.-Marc to Port-au-Prince, 4 kilometers northwest of Mont Rouis. J. S. Brown, collector. December 7, 1920.

9659 (W 110 F). Arrondissement of Port-au-Prince, Balan, southwest corner of Étang Saumâtre. W. P. Woodring, collector. November 24, 1920.

9504 (W 30 F). Arrondissement of Port-au-Prince, trail from Gantier to Fond-Parisien, 4 kilometers east of Gantier, at an altitude of 150 meters above sea level. W. P. Woodring, collector. October 20, 1920.

9591 (W 31 F). Arrondissement of Port-au-Prince, trail from Gantier to Fond-Parisien, 3 kilometers northwest of Fond-Parisien, at an altitude of 90 meters above sea level. W. P. Woodring, collector. October 20, 1920.

9539 (B 28 F). Arrondissement of Léogane, road from Léogane to Miragoâne, about 2 kilometers west of l'Acul. J. S. Brown, collector. October 22, 1920.

9576 (B 29 F). Arrondissement of Léogane, road from Léogane to Miragoâne, Source Mahot. J. S. Brown, collector. October 22, 1920.

9469 (B 30 F). Arrondissement of Léogane, road from Léogane to Miragoâne, short distance west of Source Mahot. J. S. Brown, collector. October 22, 1920.

9613 (B 35 F). Arrondissement of Nippes, trail from Miragoâne to Anse-à-Veau, about a kilometer east of village of Charlier. J S. Brown, collector. October 28, 1920.

9520 (W 103 F). Arrondissement of Nippes, trail from Miragoâne to Anse-à-Veau, about halfway between Petit-Rivière de Nippes and Anse-à-Veau. W. P. Woodring, collector. November 18, 1920.

9614 (B 36 F). Arrondissement of Nippes, roadside cut descending steep slope in town of Anse-à-Veau. J. S. Brown, collector. October 29, 1920.

9484 (B 115 F). Arrondissement of Nippes, about 300 meters east of Petit-Trou de Nippes. J. S. Brown, collector. November 22, 1920.

9637 (B 100 F). Arrondissement of Grand'Anse, trail from Les Roseaux to Corail, about 2 kilometers east of Les Roseaux. J. S. Brown, collector. November 19, 1920.

9638 (B 101 F). Arrondissement of Grand'Anse, shore line at Les Roseaux. J. S. Brown, collector. November 19, 1920.

9627 (B 74 F). Arrondissement of Coteaux, cliffs along coast 5 kilometers northwest of Port-à-Piment. J. S. Brown, collector. November 13, 1920.

9473 (B 67 F). Arrondissement of Cayes, sea cliff a kilometer northwest of Port-Salut. J. S. Brown, collector. November 11, 1920.

9474 (B 68 F). Arrondissement of Cayes, sea cliff 1.5 kilometers northwest of Port-Salut. J. S. Brown, collector. November 11, 1920.

9652 (K 22 F). Arrondissement of Aquin, trail from Aquin to Côtes-de-Fer, about 9 kilometers west of Côtes-de-Fer. W. S. Burbank, collector. November 12, 1920.

9650 (K 29 F). Arrondissement of Jacmel, trail from Bainet to Jacmel, from surface of lowest terrace. W. S. Burbank, collector. November 14, 1921.

9603 (W 63 F). Arrondissement of Jacmel, east side of Jacmel Bay about 2 kilometers southeast of Jacmel, at an altitude of 1 meter above sea level. W. P. Woodring, collector. November 1, 1920.

9514 (W 62 F). Arrondissement of Jacmel, east side of Jacmel bay, about a kilometer southeast of Jacmel, at an altitude of 50 meters above sea level. W. P. Woodring, collector. November 1, 1920.

9602 (W 61 F). Arrondissement of Jacmel, same locality as 9514, at an altitude of 60 meters above sea level. W. P. Woodring, collector. November 1, 1920.

Marine Quaternary fossils.

Species.	Port-de-Paix.		Môle St.-Nicolas.										Gonaïves.	St.-Marc.		Port-au-Prince.			Léogane.			Nippes.				Grand'Anse.		Coteaux.	Cayes.		Aquin.	Jacmel.			
	9764	9765	9841	9840	9844	9838	9837	9836	9835	9834	9833	9832	9831	9551	9479	9659	9504	9591	9539	9576	9469	9613	9520	9614	9484	9637	9638	9627	9473	9474	9652	9650	9603	9514	9602
Foraminifera:																																			
Orbiculina adunca Fichtel and Moll ?	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Corals:																																			
Madracis decactis (Lyman)	×	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Stephanocoenia intersepta (Esper)	..	..	..	..	..	..	×	..	..	..	..	×	..	..	.	×	..	..	..	..	..	..	..	..	..	..	×	..	..	..	×	..	..	..	..
Eusmilia fastigiata (Pallas)	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Dichoccenia stokesi Milne-Edwards and Haime	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	×	..	..	×	..	..	..	..	×	..	..	..	..	×	..	..	..
Dichocoenia sp., apparently new	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Meandrina maeandrites (Linnaeus)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	×	..	..	..
Orbicella annularis (Ellis and Solander)	..	×	..	×	..	..	×	..	×	..	..	×	?	×	×	..	..	..	..	×	..	×	..	..	..	..	×	×	..	×	..	×	×	..	×
Orbicella cavernosa (Linnaeus)	..	×	..	×	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Solenastrea bournoni Milne-Edwards and Haime	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Solenastrea hyades (Dana)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Maeandra labyrinthiformis (Linnaeus)	..	×	..	..	..	..	..	..	..	..	..	..	?	..	×	..	..	..	..	×	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..
Maeandra areolata (Linnaeus)	×	×	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..
Maeandra strigosa (Dana)	..	×	..	×	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	?	..	..	..	..	..	..	..	..
Maeandra clivosa (Ellis and Solander)	..	..	..	..	..	..	×	×	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	×	?	..	..
Manicina gyrosa (Ellis and Solander)	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Siderastrea radians (Pallas)	..	..	..	..	..	..	×	..	..	..	..	..	..	×	..	..	..	..	×	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..
Siderastrea siderea (Ellis and Solander)	..	..	..	×	..	..	..	..	.	..	..	×	..	×	..	..	..	×	?	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..
Agaricia agaricites (Linnaeus)	..	×	..	×	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	.	..	..	..	..
Agaricia agaricites var. purpurea (Le Sueur)	..	×	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	.	..	..	..	×
Acropora muricata (Linnaeus)	..	×	×	..	..	..	..	..	..	..	..	..	..	..	..	..	?	×	..	..	..	..	..	..	..	..	..	×	..	..	.	..	×	×	×
Acropora palmata (Lamarck)	..	..	..	..	..	..	×	..	×	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	×	×	..	..	..	..	..	×	..	..
Porites porites (Pallas)	..	..	..	..	..	..	..	..	..	..	..	..	..	×	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Porites furcata Lamarck	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	?	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Porites astreoides Lamarck	..	×	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..
Porites sp. cf. P. astreoides Lamarck	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	×	..	..

Marine Quaternary fossils—Continued.

Species.	Port-de-Paix.		Môle St.-Nicolas.										Gonaïves.	St.-Marc.	Port-au-Prince.			Léogane.			Nippes.			Grand'Anse.		Coteaux.	Cayes.		Aquin.	Jacmel.			
	9764	9765	9841	9840	9844	9838	9837	9836	9835	9834	9833	9832	9831	9551	9479	9659	9504	9591	9539	9576	9469	9613	9520	9614	9484	9637	9638	9627	9473	9474	9652	9650	9603	9514	9602
Hydrocorallinae:																																			
Millepora alcicornis Linnaeus.....	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Brachipoda:																																			
Liothyrina sp.	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Mollusca:																																			
Gastropoda:																																			
Acteocina candei (d'Orbigny) ...	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	?	..	..	..	×	..	..
Bullaria striata (Bruguière).....	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	?	..	?	..	×	..	..	..	..	..	..	..	..	..	..
Conus sp. cf. C. pygmaeus Reeve	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Oliva reticularis Lamarck.....	×	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Olivella jaspidea Gmelin ?.....	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..
Olivella sp.	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..
Marginella sp. cf. M. nivosa Hinds	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Mitra sp. cf. M. sulcata Gmelin..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Columbella mercatoria Linnaeus.	×	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Murex (Phyllonotus) pomum Gmelin ?	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..
Morum oniscus (Linnaeus).....	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Cypraea lurida Linnaeus.....	×	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Cypraea exanthema Linnaeus....	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Trivia pedicula Linnaeus.....	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Trivia sp.	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Strombus gigas Linnaeus.....	..	×	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Strombus pugilis Linnaeus.....	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..
Cerithium caudatum Sowerby....	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..
Cerithium sp. cf. C. floridanum Mörch	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Cerithium sp. cf. C. literratum Born	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

Marine Quaternary fossils—Continued.

Species.	Port-de-Paix.		Môle St.-Nicolas.											Gonaïves.	St.-Marc.		Port-au-Prince.			Léogane.			Nippes.				Grand'Anse.		Coteaux.	Cayes.		Aquin.	Jacmel.			
	9764	9765	9841	9840	9844	9838	9837	9836	9835	9834	9833	9832	9831	9551	9479	9659	9504	9591	9539	9576	9469	9613	9520	9614	9484	9637	9638	9627	9473	9474	9652	9650	9603	9514	9602
Mollusca—Continued:																																			
Gastropoda—Continued:																																			
Cerithium sp. cf. C. algicola Adams	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	×	..	..	..	..	..	..
Cerithium sp. cf. C. nigrum Born	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..
Cerithium sp.	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..
Modulus floridanus Conrad ?	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..
Petaloconchus sp. cf. P. irregularis (d'Orbigny)	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Caecum sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..
Hydrobia sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Xenophora conchyliophora Born ?	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×
Natica sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..
Polinices lactea Guilding	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Polinices sp.	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Astraea caelata (Gmelin)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..
Astraea americana (Gmelin)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Cittarium picum (Linnaeus)	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Phasianella affinis Adams ?	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	×	..	..	..	..	..	..	..	..	..	..
Calliostoma indusii Gmelin	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Calliostoma sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..
Nerita sp. cf. N. tessellata Gmelin	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Neritina virginea Lamarck	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..
Neritina sp.	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Fissuridea cancellata Sowerby	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Fissuridea barbadensis Gmelin	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Fissuridea sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..
Subemarginula octoradiata (Gmelin)	×	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

Marine Quaternary fossils—Continued.

Species.	Port-de-Paix.		Môle St.-Nicolas.										Gonaïves.	St.-Marc.		Port-au-Prince.			Léogane.			Nippes.			Grand'Anse.		Coteaux.	Cayes.		Aquin.	Jacmel.			
	9764	9765	9841	9840	9844	9838	9837	9836	9835	9834	9833	9832	9831	9551	9479	9659	9504	9591	9539	9576	9469	9613	9520	9614	9484	9637	9638	9627	9473	9474	9652	9650	9603	9514	9602
Scaphopoda:																																			
Dentalium sp. cf. D. semistriolatum Guilding	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Pelecypoda:																																			
Arca umbonata Lamarck	×	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	.	..	..	..	?	..	..	..	..	..	..	..	..	..	..	..	..
Barbatia candida (Gmelin)	×	..	..	..	..	..	..	..	..	..	..	..	..	..	?	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Scapharca auriculata (Lamarck)	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Scapharca deshayesi (Lamarck)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..
Glycymeris pennacea (Lamarck)	×	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Glycymeris sp. cf. G. pectinata (Gmelin)	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Glycymeris sp.	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Atrina sp.	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Ostrea folium Linnaeus	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Ostrea sp.	×	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..
Chlamys (Chlamys) imbricatus (Gmelin)	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Chlamys (Aequipecten) sp.	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..
Chlamys (Plagioctenium) sp. cf. C. (P.) gibbus (Linnaeus)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	×	..	..	..	..	..	..
Spondylus americana Lamarck	?	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Lima scabra Born	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Mytilus sp.	×	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Chama macerophylla Gmelin	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	?	..	..	..	..	..	..	..	..	..	..	..
Cocakia (Codakia) orbicularis (Linnaeus)	?	×	..	..	..	..	..	..	..	..	..	?	..	×	..	..	..	..	..	..	..	..	..	..	?	..	..	..	..	..	..	..	..	..	..
Codakia (Jagonia) sp.	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Lucina sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..
Phacoides (Here) pennsylvanicus (Linnaeus)	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	?	..	..	..	..	..	..	..	..	..	..	..	..	..	?

Marine Quaternary fossils—Continued.

Species.	Port-de-Paix.		Môle St.-Nicolas.										Gonaïves.	St.-Marc.	Port-au-Prince.			Léogane.			Nippes.				Grand'Anse.		Coteaux.	Cayes.		Aquin.	Jacmel.			
	9764	9765	9841	9840	9844	9838	9837	9836	9835	9834	9833	9832	9831	9551	9479	9659	9504	9591	9539	9576	9469	9613	9520	9614	9484	9637	9638	9627	9473	9474	9652	9650	9603	9514	9602
Pelecypoda—Continued:																																			
Phacoides (Callucina) radians (Conrad)	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Phacoides (Parvilucina) sp. cf. P. (P.) lintea Conrad	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	?	..	..	..	..	..	..	..	..	..	..	..	..
Divaricella quadrisulcata d'Orbigny	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	?	×	..	..	..	..	..	..	..	..	..	..
Diplodonta sp. cf. D. candeana d'Orbigny	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..
Cardium (Fragum) medium Linnaeus	×	..	..	..	..	..	.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Cardium (Papyridea) sp. cf. C. (P.) spinosum Meuschen	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Protocardia sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Dosinia elegans Conrad	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..
Pitar sp.	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Cytherea (Ventricola) rigida (Dillwyn)	×	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Chione cancella Linnaeus	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..
Chione (Lirophora) paphia Linnaeus	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	×	..	..	..	×	..	..	..	..	..	..
Coralliophaga sp.	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Tellina (Tellina) interrupta Wood	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Tellina (Eurytellina) georgiana Dall.	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..
Tellina (Angulus) sp. cf. T. (A.) promera Dall	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Tellina (Cyclotellina) fausta Donovan	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..
Tellina sp.	..	×	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..
Strigilla rombesgii Mörch	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	?	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..
Macoma ? sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..
Corbula sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..
Decapod Crustacea:																																			
Mithrax sp.	..	..	..	..	×	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

Nonmarine Deposits.

The nonmarine Quaternary deposits consist of stratified but generally poorly sorted silt, clay, sand, or gravel deposited by streams. The material of which they are composed is usually identified as derived from adjacent highlands. They are unconsolidated, and although the beds in many places have a slight initial dip, equivalent to that of the slope on which they were deposited, they are not deformed. No attempt was made to separate Pleistocene and Recent deposits. In general the older (probably Pleistocene) deposits are more dissected than the younger deposits. It is equally difficult to distinguish the Quaternary deposits from similar deposits of Pliocene age. The degree of dissection and the general geologic history have been utilized in attempting this separation.

The presence of nonmarine Quaternary gravels at the landward margin of the marine Quaternary deposits and the reasons for their apparent or actual absence at many places have been mentioned on page 245.

Extensive areas of sands and gravels of Quaternary age are found on some of the plains adjoining the sea, particularly in the eastern part of the North Plain, east of the longitude of Fort Liberté. Here they floor a dissected plain, and a thin veneer of gravels covers parts of the rock platform that extend along the mountain front to the south. (For description of surface features see pp. 356-358.) The deposits consist of unconsolidated gravels, sands, and clays, derived chiefly from eroded and weathered products of the quartz diorite, which crops out in the mountains and on the platform on which the deposits lie. The beds have a gentle seaward slope, parallel to the surface of the plain. The beds of sand and gravel are lenticular and cross-bedded. The clay is fine and dark, and at places it contains indeterminable fragments of plants. On the plain northeast of Acul Samedi, where the deposits are well exposed, the sands and gravels cap small mesas. Near the surface the sandy beds are at places cemented into relatively hard sandstones by iron and manganese oxides. Residual concretionary masses of these oxides are scattered on the surface. (See pp. 477-478.)

The deposits probably were laid down by streams during the retreat of the sea after the cutting of the rock platform. More careful study might show that some of the beds are marine. Coral reefs and coralliferous limestones, probably of Quaternary age, were found on the eastward prolongation of the plain near Copey, in the Dominican Republic.[1]

Other unconsolidated gravels and sands of Quaternary age occupy considerable areas in the interior, generally at the foot of high mountain ranges or in interior valleys and plains.

Quaternary deposits cover stream terraces along the large streams. The most extensive terrace deposits are in the drainage basin of Rivière Arti-

[1] A geological reconnaissance of the Dominican Republic: Dominican Rep. Geol. Survey Mem., vol. 1, pp. 165, 174-175, 1921.

bonite. The terraces are described on pages 380-385. The separation of the Pliocene Hinche formation from the Quaternary terrace deposits in the Central Plain may be artificial. In general the Quaternary deposits here contain a greater proportion of large cobbles and boulders of limestone and brown or black chert derived from the surrounding mountains.

Similar terrace deposits are widespread in the Artibonite Valley. Along the trail from Mirebalais to Saut d'Eau the deposits on the west side of Rivière Tombe consist of gravel, coarse sand, and lenses of white marl. At places boulders of chert and basalt larger than a man's head are strewn on the surface. These deposits are as much as 30 meters higher than the stream and are well dissected. The land gastropods listed on page 257 (station 9457) were collected from coarse sand 25 meters above the stream at a locality about 5 kilometers southwest of Mirebalais. Fresh-water and land gastropods were collected from silt a kilometer southeast of Mirebalais, on the road to Las Cahobas. (See list, p. 257, station 9902.) Some of these stream deposits may be of the same age as the Hinche formation of the Central Plain, but more detailed work would be required to separate Pliocene and Quaternary deposits.

In the lower part of the Artibonite Valley Quaternary terrace gravels extend along the north side of the river. At places the surface is strewn with boulders and cobbles. (See Pl. XXX, *A*, p. 386.) On the south side of the river a narrow band of gravels extends downstream from Les Verrettes. Northwest of the road from St.-Marc to Gonaïves the gravels grade into conglomeratic coralliferous limestone.

The relations of the Quaternary gravels near Port-au-Prince to the water supply of the city are discussed on pages 571-573.

The nonmarine Quaternary deposits are similar to the marine in showing a peculiar hardening near the surface, which causes them to resemble much older and more consolidated rocks. The process is essentially the same as with the marine deposits. Near the surface the bedding usually is destroyed by this process, which is assisted by slump and creep. A typically hardened surface is shown in Plate XVII, *B*. This effect is not noticeable more than 2 or 3 meters below the surface of the ground.

The thickness of the nonmarine Quaternary deposits is perhaps even more variable than that of the marine. Only at a few places, probably, does it exceed 50 meters.

FOSSILS.

Land and fresh-water mollusks are the only invertebrate fossils obtained from nonmarine deposits of Quaternary age. Most of the land mollusks, which were examined by the late Mr. John B. Henderson, of the United States National Museum, are similar to species now living in Haiti.

Stations near Mirebalais (nonmarine Quaternary).

9457 (W 135 F). Arrondissement of Mirebalais, trail from Mirebalais to Saut d'Eau (Ville Bonheur), about 5 kilometers southwest of Mirebalais. W. P. Woodring, collector. December 7, 1920.

9902 (W 181 F). Arrondissement of Mirebalais, road from Mirebalais to Las Cahobas, about a kilometer east-southeast of Mirebalais. W. P. Woodring, collector. January 8, 1921.

Nonmarine Quaternary fossils collected near Mirebalais.

Species.	9457	9902
Gastropoda:		
Limnaea sp.	....	×
Cepolis (Plagioptychus) indistincta Ferussac	....	×
Pupoides marginatus nitidulus Pfeiffer	....	×
Obeliscus sp.	....	×
Obeliscus (Dolicholestes) sp., apparently different from any described West Indian species	×	....
Pleurodonte (Parthena) sp. cf. P. (P.) angusta Ferussac	×	....
Pleurodonte (Parthena) undulata Ferussac	×	....
Pleurodonte (Luquilla) sp. cf. P. (L.) audelbardi Pfeiffer	×	....

Extinct Quaternary Mammals and Birds.

Extinct Quaternary mammals, principally rodents, ground sloths and bats, have been found in caves and kitchen middens in Cuba, Porto Rico, and other West Indian islands. Miller[1] has described three rodents, belonging to the genera *Isolobodon, Plagiodontia,* and *Brotomys,* from kitchen middens at San Pedro de Macorís and San Lorenzo in the Dominican Republic. During the reconnaissance of the Republic of Haiti a preliminary examination was made of two caves in the arrondissement of Marmelade in order to determine whether a similar fauna could be discovered in the Republic. The results fully justified the preliminary exploration and indicate that more extensive exploration of these and other caves in the Republic is warranted.

The caves examined are on the south slope of the mountains northeast of St.-Michel de l'Atalaye and northwest of the plantation of the United West Indian Corporation. The mountains here consist of limestone of middle Eocene age. In this region there are a large number of caves, formed during a period when the drainage systems were different from the present. Many of the caves stand high on the mountain slope and have no apparent relation to the present drainage, either surface or subterranean. There is little evidence of active solution. The caves are dry and are apparently being filled with residual clay, rain-washed débris, and other material. Many of them contain a thick floor cover of guano left by the thousands of bats that now inhabit or recently inhabited them.

[1] Miller, G. S., jr., Bones of mammals from Indian sites in Cuba and Santo Domingo: Smithsonian Misc. Coll., vol. 66, no. 12, 10 pp., 1 pl., 1916.

The larger of the two caves explored is about 3 or 4 kilometers northeast of St.-Michel de l'Atalaye and the same distance northwest of the plantation. It stands about 600 meters above sea level, nearly 200 meters above the Central Plain, which adjoins the mountains to the south. Its length is about 40 meters and its width and height 10 to 20 meters. Several large columns, formed by the union of stalactites and stalagmites, extend from the floor to the roof. The cave has two large openings, separated by a pillar, and a third small opening on the sloping hillside, which affords entrance nearly on the plane of the floor. Near the rear of the cave there is an opening or skylight, about 5 meters in diameter, through which long roots of figuier trees extend. Fragments of rock and surface wash falling down the skylight have built up a small cone of coarse débris beneath it. An excavation nearly 2 meters deep and a little more than a meter in diameter was made in the middle of one of the largest open spaces. Only firm, dry, reddish dirt was encountered. The rock floor appears to be very deep here and was not approached in this pit. Another hole was made near the rear end of the cave, about a meter from the wall and 5 meters from the cone of débris near the skylight. The excavation was less than a meter deep and about a meter in diameter. Rocks and boulders were embedded in the cave earth. From very near the surface downward this hole yielded bones.

The smaller cave examined is about 2 kilometers north-northwest of the plantation and perhaps 2 kilometers east of the first cave, on the south side of a deep dry ravine. The diameter of the opening is about 30 meters. The roof is arched, all in one chamber, and the floor is convex, the rear half being nearly bare rock, partly covered by a thin deposit of bat guano. The mouth, which was formerly much larger, is choked by a pile of débris from the cliff that rises above it. This débris has rolled inward as well as outward, covering the floor of the front part of the cave. An excavation was made at the lowest part of the cave adjacent to one of the vertical rock walls, following down the wall to a depth of nearly 2 meters. At the bottom the rock wall sloped inward steeply, and the entire floor of the excavation was on rock. The material excavated consisted of loose stones, between which lay dirt and guano. Bones were found from a depth of 0.6 meter to the bottom, increasing in number downward.

The bones obtained are the remains of mammals and birds. The mammals have been examined by Mr. G. S. Miller, jr., of the United States National Museum, and the birds by Mr. Alexander Wetmore, of the Biological Survey, United States Department of Agriculture. Papers containing descriptions of the remains have recently been published.[1] The remains identified by Miller and Wetmore are tabulated below.

[1] Miller, G. S., jr., Remains of mammals from caves in the Republic of Haiti: Smithsonian Misc. Coll., vol. 74, no. 3, 8 pp., 1922. Wetmore, Alexander, Remains of birds from caves in the Republic of Haiti: Smithsonian Misc. Coll., vol. 74, no. 4, 4 pp., 2 text figs., 1922.

Mammals:
  Rodents:
    Isolobodon portoricensis Allen.
    Aphaetreus montanus Miller n. gen. and n. sp.
    Ithydontia levir Miller n. gen. and n. sp.
    Brotomys voratus Miller?
  Ground sloth:
    Megalocnus?
Mammals:—Continued.
  Man:
    Homo sapiens (head of left femur).
Unidentified fragments.
Birds:
  Chaemepelia passerina (Linnaeus).
  Crotophaga ani Linnaeus.
  Tyto ostologa Wetmore n. sp.
  Tolmarchus gabbii (Lawrence).

Rodents of the genus *Isolobodon* furnished the most abundant remains in both caves. The new genus *Aphaetreus* is represented by a mandible with a full set of cheek teeth, and the new genus *Ithydontia* by isolated teeth, all of which were collected in the larger cave. A small ground sloth, probably resembling the extinct *Megalocnus* of Cuba, is represented by a nearly perfect caudal vertebra, an imperfect probably dorsal vertebra, a fragment apparently of the proximal end of the radius of a young animal, all obtained in the larger cave; and by two imperfect caudal vertebrae and the proximal end of a fragment of the shaft of a rib, collected in the smaller cave. The human remains consist of the head of a left femur found at the same level with the remains of the ground sloth in the smaller cave. The bone substance is lighter and less infiltrated with mineral matter than the bones of the sloth. A chipped chert, identified by Mr. Walter Hough, of the United States National Museum, as a human artifact, was found at an undetermined level in the same cave. The human remains are probably younger than the others. The unidentified fragments include parts of a foot of perhaps a large rodent and a piece of a large bone, probably of a ground sloth.

Three of the birds—a dove (*Chaemepelia*), an ani (*Crotophaga*), and a petchary (*Tolmarchus*)—are now found in the Republic. The fourth, *Tyto ostologa,* is a very remarkable extinct gigantic barn owl, represented by the head of a metatarsus and other fragments. Evidently this bird was the marauder that brought into the caves the rodents whose bones are found there in such large numbers. Some of these rodents are so large that no living owl of the Republic could handle them.

Aside from the interesting discovery of the unknown gigantic owl, the remains obtained from the excavations increase our knowledge of the extinct early Quaternary mammalian fauna of the West Indies. Although no carnivores or ungulates have yet been found, the known fauna is becoming more and more diversified with each exploration. The extinct Haitian mammals support Miller's suggestion [1] that the West Indian early Quaternary mammals descended directly from a South American fauna probably not older than Miocene. This suggestion harmonizes with the view that during late Miocene time the West Indian lands were more extensive than now and probably were directly connected with Central America, and that they were separated into islands during Pliocene time.

[1] Miller, G. S., jr., op. cit., p. 4, 1916.

IGNEOUS ROCKS.

By Wilbur S. Burbank.

GENERAL DISTRIBUTION.

Igneous rocks crop out in probably a little more than one-fifth of the total area of the Republic. The largest areas are in the Massif du Nord and in the ranges of the Southern Peninsula. Relatively few exposures are found in the central ranges and intervening plains. Most of the igneous rocks are older than the Tertiary sedimentary rocks and are now exposed principally on the eroded crests of anticlinal arches and in deep valleys where the sedimentary rocks have been removed. The areal distribution of the igneous rocks is shown on the geologic map (Pl. I.)

The igneous rocks are discussed under the heading of extrusive rocks, or those that have poured out on the surface of the earth, and of intrusive rocks, or those that have been injected into or have penetrated between other rocks and solidified without reaching the surface. As it is not always possible in the field, especially among the older rocks, to distinguish between extrusive and intrusive rocks, certain rocks of doubtful origin are either classified on textural and other features, or are discussed with other rocks of known origin that accompany them.

The geology of the igneous rocks is relatively complex. Notable differences are found both in the rocks and in the igneous history of the northern and southern parts of the country. The early igneous history of the central part of the country is obscured by the overlying Tertiary formations, but its later Tertiary history has some distinctive features. Both because of convenience in discussion and because of petrologic considerations, the igneous rocks of the Republic will be discussed under three geographical divisions:

1. The northern region (see Pl. XXVII), comprising Tortue Island, the North Plain, the Massif du Nord, the Northwest Peninsula, the northwestern part of the Montagnes Noires, the northern part of the Central Plain, and the northern extremity of the Artibonite Plain.

2. The central region, comprising the southern part of the Central Plain, the southeastern part of the Montagnes Noires, the southern part of the Artibonite Plain, the Montagnes du Trou d'Eau, and the Chaîne des Mateux.

3. The southern region, comprising the Massif de la Selle and the Massif de la Hotte.

The general boundaries of these regions are shown on the geologic map, although naturally they can not be sharply drawn. A summary of the igneous activity and of the tectonic history of these three regions is given in the following table:

Summary of the igneous activity and tectonic history.

Time subdivisions.	Northern region.	Central region.	Southern region.
Pliocene	Emergence	Emergence	Minor submergence and continuation of folding.
Upper Miocene ...	Emergence and folding. Intrusion of quartz diorite in Monts. de Terre-Neuve.	Emergence and intense folding.	Emergence and folding.
Lower and middle Miocene.	Marginal submergence. Marls and coralliferous limestones.	Nearly complete submergence. Minor eruptions of basalt, interbedded in marl.	Marginal submergence.
Upper Oligocene ..	Partial submergence followed by emergence.	Extensive submergence. Limestones. Eruption of nephelite basalt. Partial emergence.	Emergence.
Middle Oligocene .	Partial submergence	Extensive submergence..	Local submergence.
Lower Oligocene ..	Emergence and folding..	Probable emergence	Emergence and folding.
Upper Eocene	Extensive submergence. Limestones.	Complete submergence. Limestones.	Complete submergence. Limestones.
Middle Eocene	Partial submergence	Emergence	Emergence.
Lower Eocene	Emergence and extensive erosion. (?) Minor eruptions of basalt, andesite, diabase, essexite. Exact age unknown.	Emergence and extensive erosion.	Emergence and extensive erosion.
Upper Cretaceous.	Batholithic intrusions of quartz diorite. Intense folding. Local submergence. Limestones.	Basalts and tuffs, probably of this age. Probably partial submergence.	Folding. Extensive fissure eruptions of basalt, partly submarine. Partial submergence. Limestones.
Lower or middle Cretaceous.	Partial submergence. Sandstones, shales, argillites, non-marine and marine.	.....	Partial submergence. Argillaceous limestones and shales.
Jurassic	Emergence. Extensive volcanic activity. Eruption of andesites and dacites.	.....	Emergence (?). No evidence of igneous activity.
Early Jurassic or Triassic (?).	Eruptions of basaltic lavas and minor intrusions of basic and ultrabasic rocks.		

OUTLINE OF THE IGNEOUS GEOLOGY.

Northern region.—The northern system of mountains in the Republic of Haiti, here called the Massif du Nord, is characterized by a core of large bodies of massive quartz diorite, probably of middle or late Cretaceous age. These granitic rocks intrude and metamorphose lavas of Mesozoic age and some older metamorphic sediments, possibly of Paleozoic age. The mountain ranges of the Northwest Peninsula also contain some bodies, of unknown size, of similar granitic intrusives.

Apparently the oldest Mesozoic lavas are basalts. Associated with them are some pyroxenites, peridotites, and diabasic intrusives, which are probably of nearly the same age. Near the quartz diorite batholith these older rocks have been subjected to contact metamorphism and are converted locally into amphibolites and serpentinous amphibolites or into amphibole, talc, and chloritic schists. The alteration of the pyroxenites and peridotites is somewhat in contrast to that of similar rocks in Cuba, where the formation of serpentine was the most common alteration. Most of the earlier basaltic rocks have suffered more or less metamorphism, and many are converted to "greenstones." Olivine-free and hypersthene basalts and porphyritic basalts rich in pyroxene and containing some olivine seem to be the more common types. The age of these basalts is possibly Jurassic or older.

The younger and more extensive Mesozoic lavas are chiefly andesites but include some dacites. They are found throughout nearly the length of the Massif du Nord and are remarkably uniform in composition and texture. The apparent lack of more diverse types of lava in association with the andesites and dacites is noteworthy. Where they have been intruded by the quartz diorite these lavas have been locally metamorphosed but not to the extent of the older basaltic rocks. The more common varieties seem to be pyroxene andesites, hornblende-augite andesites, and hornblende andesites; hypersthene andesites and hornblende-biotite andesites are less common. The quartz-bearing varieties of lava include pyroxene dacites, hornblende-augite dacites, and hornblende-biotite dacites. Some of the lavas that contain only a little quartz should possibly be classified as quartz-bearing pyroxene andesites. The eruption of the andesites and dacites in the central part of the Massif du Nord certainly took place prior to the deposition of certain sedimentary rocks that are considered Lower or Middle Cretaceous, but in the Montagnes Noires the lavas appear locally to have buried similar sediments. However, no lava flows have been found definitely interbedded in the Cretaceous (?) sedimentary rocks. Probably the eruptions occurred largely in the Jurassic period, but in some regions they extended at least into the lower Cretaceous, and minor undiscovered eruptions may be even later.

Basaltic lavas and intrusive rocks, some of them alkaline, have a rather local distribution in the western part and along the southwestern

border of the Massif du Nord. At several localities these rocks seem to be younger than the andesites, but their relation to the quartz diorite was not determined at any place. Calcareous sediments containing Foraminifera of unknown age are in places associated with these lavas and are locally engulfed or included in pillow lavas of this series. The varieties of rock include amygdaloidal basalts, olivine basalts and diabases, analcite andesites, analcite-olivine andesites, and essexite. Some of the rocks are much zeolitized. The more or less alkaline varieties are rather common and are widely distributed. The age of the eruptions may have been late Cretaceous or early Eocene, but the evidence warrants only very general conclusions.

The major igneous intrusion occurred in middle or late Cretaceous time and consisted of large bodies of quartz diorite of rather uniform composition. In the eastern part of the Massif du Nord, where it is extensively exposed, the quartz diorite contains hornblende and chlorite. In the Northwest Peninsula altered porphyritic facies of the intrusive rock locally contain mica. Some lamprophyric dikes and veins of quartz hornblendite cut the main body of the batholith.

Intrusions of minor stocks of quartz diorite, granodiorite, and associated porphyries occurred probably during the Miocene along the central arch of the Montagnes de Terre-Neuve. These rocks invaded the Mesozoic andesitic lavas and the overlying upper Eocene limestones. The intrusives where exposed are principally the fine-grained porphyries. There are also some associated dikes of porphyry and veins of pegmatite.

In a general way the igneous rocks of the northern part of the Republic are similar in many features to those of the Western Cordillera of South America and to those of the Pacific Coast ranges of North America. The prevalence of andesites and dacites among the volcanic rocks is a characteristic feature of the Western Cordillera of South America. An analysis of a pyroxene andesite from the Terre-Neuve region (p. 276) shows relatively higher silica and lower potassium oxide than the average andesite. The high percentage of quartz and the practical absence of orthoclase in the quartz diorite from the central part of the Massif du Nord is also particularly noteworthy. The Cretaceous quartz diorite of the Northwest Peninsula and the Miocene (?) intrusives of the Montagnes de Terre-Neuve are higher in potash feldspar than the principal body of quartz diorite. All the rocks are rather high in titanium.

Quartz and hornblende bearing granitic intrusives are widespread in the West Indies and are found in the islands of Cuba, Porto Rico, Vieques, St. Thomas, and St. Martin.[1] They are both pre-Cretaceous and post-Cretaceous in age.[1]

Central region.—In the central ranges and plains of the Republic the pre-Tertiary igneous rocks are rarely exposed. Small patches of glassy

[1] Vaughan, T. W., unpublished notes.

hypersthene basalts are exposed along the central arch in the southeastern part of the Montagnes Noires. These lavas are older than upper Eocene. Small areas of early or pre-Tertiary igneous rocks are exposed in the central part of the Chaîne des Mateux.

Nephelite basalts are found at several localities in the Montagnes du Trou d'Eau. Flows and explosive eruptions of these lavas took place probably from isolated central vents. In composition the rocks are largely or entirely nephelite basalt. Some varieties contain haüynite or melilite and others are much zeolitized. Rocks of similar composition (p. 316) have been found in Grenada[1] and in Uvalde County, Texas.[2] The nephelite basalts northeast of Thomazeau are of middle or upper Oligocene age; basalts near Saut d'Eau are post-middle Oligocene and may be younger than the others, but their relations to the Miocene beds of the Artibonite Valley are not known. In the Dominican Republic limburgite, probably of Pleistocene age, has been found.[3]

Minor amounts of basaltic lavas and débris are interbedded in the Miocene sedimentary rocks on the western flank of the Chaîne des Mateux and in the southwestern part of the Montagnes du Trou d'Eau.

Southern region.—The principal igneous rocks found in the mountain ranges comprising the Southern Peninsula of Haiti are basaltic lavas. These lavas are exposed in the central arch of the mountains or in deep valleys cut in the Tertiary limestones. The lavas have buried older limestones and argillaceous rocks, probably partly of Cretaceous age, and together with these comprise a basement on which the Tertiary limestones lie. Probably only a part of the original extent of the eruptions is included by the present outline of the Southern Peninsula. The eruptions were doubtless for the most part of the fissure type, as pyroclastic débris is found only locally. Ordinary basalts are the most common variety of lava, but olivine basalts, spilitic basalts, diabase porphyries, and augite andesites are also found. Some of the lavas are amygdular and many have pillow structure. Large amounts of tuff and agglomerate are exposed in the northwestern part of the Massif de la Selle. An analysis of an ordinary basalt from the Massif de la Selle (p. 325) shows that the lava is unusually high in calcium oxide and rather high in titanium. One of the noteworthy features of the analysis is the very high ferrous iron, showing that the lavas were probably fluid.[4] The eruptions doubtless occurred in Upper Cretaceous time, as the lavas have buried argillaceous limestones that are considered Lower or Middle Cretaceous, and pillow lavas have locally buried or intruded unconsolidated calcareous deposits that are

[1] Harrison, J. B., Rocks and soils of Grenada and Carriacou, p. 10, London, 1896.

[2] Osann, A., Melilite-nephelite basalt and nepheline basanite from Southern Texas: Jour. Geol., vol. 1, pp. 341-346, 1913. Vaughan, T. W., and Cross, W., U. S. Geol. Survey Geol. Atlas, Uvalde Folio (No. 64), pp. 3-5, 1900.

[3] Condit, D. D., and Ross, C. P., Dominican Rep. Geol. Survey Mem., vol. 1, p. 203, 1921.

[4] Washington, H. S., Deccan traps and other plateau basalts: Geol. Soc. America Bull., vol. 33, pp. 765-804, 1922.

supposed to be Upper Cretaceous (pp. 96-97). The lavas lie unconformably beneath upper Eocene limestones.

Hypersthene and hornblende andesites are found near Baradères in the Southern Peninsula. They comprise only a small group of rocks, and their relations to the basalts are unknown. They are probably, like the basalts, of late Cretaceous age.

NORTHERN REGION.

Extrusive Rocks.

GENERAL FEATURES AND DISTRIBUTION.

The extrusive rocks of the northern region are principally lavas. Although they include some interbedded breccias and tuffs, no thick deposits of such rocks were seen except in the western part of the Northwest Peninsula, where some tuffaceous and agglomeratic rocks of unknown thickness underlie limestone of supposed upper Eocene age. A large part of the detrital volcanic rocks have probably been reworked and deposited in water. The lavas form the larger part of the igneous rocks in the northern region and in general range in composition from basalts to dacites, but may include more basic or more acidic rocks.

The thickness of the extrusive series is unknown but is probably variable in different parts of the region, and at some places is undoubtedly very great. No reliable estimate of the thickness is possible at present, as the basement on which the lavas rest has not been definitely recognized in outcrops. In the western part of the Massif du Nord the thickness probably is more than 1,000 meters. The original thickness of the series may have considerably exceeded 1,000 meters in some places, as in addition to their erosion in the present cycle these rocks underwent erosion during long periods in both Cretaceous and early Eocene time, parts of the later volcanic accumulations probably having been removed during each period. In some regions a part of the series has also been engulfed in a Cretaceous batholithic intrusion of quartz diorite.

In the eastern part of the Massif du Nord the volcanics flank the intrusive quartz diorite along its entire southern boundary, and a band of metamorphic volcanic rocks extends along the north side from Grande-Rivière du Nord eastward to Les Perches. East of Les Perches they were largely engulfed in the quartz diorite, although small patches are still preserved and in places crop out through the alluvial deposits of the North Plain. (See Fig. 18, *A* and *B*, p. 311.) In the western part of the Massif du Nord, west of the Grande Rivière du Nord, the volcanic rocks comprise 80 to 90 per cent or more of the exposed igneous rocks. A small area of volcanic rocks is found at the border of the Central Plain north of Hinche. Northwest of the plain, near St.-Michel de l'Atalaye and Ennery, small patches of the underlying lavas are exposed in the areas of Eocene limestones.

In the northern part of the Montagnes Noires and outlying parts of the Artibonite Plain, lavas apparently constitute the bulk of the igneous rocks and are exposed in the deeper valleys and along the tilted northwest front of the mountains.

The igneous rocks in the Montagnes de Terre-Neuve are predominantly lavas In the extreme western part of the Northwest Peninsula small areas of the lavas and pyroclastic rocks underlie the upper Eocene limestone.

AGE OF ERUPTIONS.

The longest periods of volcanic activity were clearly pre-Tertiary, and as lavas of these periods near Grande-Rivière du Nord and Dondon are unconformably overlain by argillites of supposed Lower Cretaceous age and by Upper Cretaceous limestone the earlier periods can be referred back to pre-Cretaceous time. Little or no evidence was found to show how long before Cretaceous time the volcanic activity may have existed. Much of the activity was probably of Jurassic age, but at least the later part of it may have been of Lower Cretaceous age, as hornblende andesites in the Montagnes Noires southwest of St.-Michel appear to cover sedimentary rocks tentatively correlated with the Cretaceous series.

No positive evidence of igneous activity in middle or upper Eocene time was found. Except for usually thin basal beds, composed largely of detrital igneous material, the Eocene sedimentary rocks are principally limestones. The basal conglomerate of the Plaisance limestone (middle Eocene) exposed at the northeast base of Mont Puilboreau and between Ennery and St.-Michel de l'Atalaye contains rounded pebbles and boulders of the underlying volcanic rocks (see pp. 272, 102, and Fig. 18, *C*, p. 311). This material was derived by erosion from the underlying volcanic basement. In the western part of the Montagnes de Terre-Neuve the basal part of the Eocene limestone, for a thickness of several hundred meters, contains interbedded sandy layers of igneous material. This material appears to be waterworn sand and pebbles and was derived by erosion from an igneous landmass above sea level probably in what is now the central part of the Montagnes de Terre-Neuve. (See pp. 113-115.) In the extreme western part of the Northwest Peninsula, at Morne Chien, between Baie de Henne and Bombardopolis, a small amount of sandy material derived from igneous rocks is interbedded in the basal parts of limestone of supposed upper Eocene age. The sandy basal beds immediately overlie tuffaceous and agglomeratic volcanic débris. The igneous material in the sandy limestone apparently was not a product of contemporaneous volcanic activity but was derived by erosion from the underlying tuff. About 10 to 12 kilometers farther west, near Plateforme, according to Lütgens,[1] ash, tuffs, and basalt flows are interbedded with metamorphosed marly

[1] Lütgens, R., Geographische und geologische Beobachtungen in Nordwest-Haïti: Geog. Gesell. in Hamburg Mitt., Band 32, pp. 72-75, 1919.

limestone. Although Lütgens has apparently misjudged the age of the limestone and basalt, which, from lack of paleontologic data, he calls Pliocene, his sections and descriptions appear to indicate that basal parts of the upper Eocene limestone and the underlying volcanic débris are exposed near Plateforme. (See also pp. 112 and 370.) However, great thicknesses of interbedded tuffs are found farther west in the upper Eocene limestone of the Sierra Maestra of Cuba.

The upper limits of age of the principal periods of volcanic activity can thus be placed at middle Eocene and in most places at upper Cretaceous. There is little or no evidence to show how far back in the Mesozoic the earlier volcanic eruptions took place. The intense local metamorphism produced during the batholithic intrusion of quartz diorite near the close of Cretaceous time renders the criterion of metamorphism of rather doubtful value. Certain schists that possibly consist of remnants of the basement upon which the lavas were erupted show a degree of metamorphism much greater than that found in any of the volcanic rocks or other rocks in which the metamorphism can be definitely attributed to the period at the end of Cretaceous time. (See pp. 84, 85.) If it is assumed that these schists are of early Mesozoic or of late Paleozoic age, the principal periods of volcanic activity must be referred to early or middle Mesozoic time, to the Triassic, Jurassic, or Lower Cretaceous. In certain areas later basaltic eruptions may be as young as late Cretaceous or early Eocene. (See p. 280.)

ORDER OF ERUPTION.

The Mesozoic igneous activity was so complex that only the general features of its history can be determined. At critical localities the older rocks may be covered by the Tertiary and Cretaceous sedimentary rocks, and erosion during Cretaceous and Eocene time has removed many of the later volcanic accumulations. Detailed work would be required to establish accurately the relations of the rocks in these series, but a few of the more important features of the igneous history are recognizable. The major eruptions apparently were marked by enormous outflows of lava from a large number of central vents or fissures, which at times probably covered much of the northern and central part of the island of Haiti, including what is now the northern part of the Republic. The landmass at the time of these eruptions was presumably very much greater than at present. The uniformity of the lavas in the northern part of the Republic indicates large reservoirs of a common magma from which they were derived.

The earliest known eruptions were basaltic. At many places the older basaltic rocks are associated with metamorphic rocks and schists, some of which are presumably the result of local metamorphism of the igneous rocks or of associated tuffs and sediments. The schists at some localities

may, however, be much older. Peridotites and pyroxenites (?) are found at some localities with the basalts and probably are intrusive into them. The rocks of these earlier periods of activity are generally characterized by much metamorphism and alteration, as they were buried to considerable depths under accumulating volcanic and sedimentary rocks and were intensely affected by the folding and batholithic intrusions at the close of Cretaceous time. These earlier periods of basaltic eruptions may have been of Jurassic age or even older.

Later eruptions consisted largely of pyroxene andesites and dacites. Events separating these later eruptions from the earlier periods of activity are obscure. Neither accumulations of sedimentary material nor evidences of erosion were definitely recognized. In the Montagnes de Terre-Neuve the pyroxene andesites apparently overlie a basement containing shales and metamorphic limestone, but the older basalts are not present in the section. Whether the eruptive periods were continuous or were separated by an interval of quiescence, the lavas of the later eruptions are uniformly andesitic or dacitic, presumably indicating important changes in the parent magmas from which the eruptive rocks were derived. Probably many of the later lavas of this series were dacites. The age of the andesitic and dacitic lavas is considered Jurassic or possibly in part Lower Cretaceous.

Hornblende and pyroxene andesites and some olivine-bearing andesites that are found in the northwestern part of the Montagnes Noires are of unknown age, but from their petrographic character they are tentatively assigned to the period during which the andesites were erupted in the Massif du Nord and the Montagnes de Terre-Neuve.

At the southern border of the northern region, in a belt extending from St. Michel northwestward through Ennery, including the Montagnes de Terre-Neuve and the region around Gros-Morne, there is a series of younger basaltic lavas and intrusive rocks. These rocks are younger than the pyroxene and hornblende andesites of the Terre-Neuve mountains and are clearly younger than the hornblende andesite between Gonaïves and Ennery. They may be of Cretaceous or early Eocene age.

Among the later eruptives that reached the surface in the northern region is a series of dacite porphyries, which engulfed and possibly overflowed Cretaceous argillites southwest of St.-Michel in Section Paul. Because of their petrographic character and possible intrusive relations these rocks are tentatively correlated with the quartz-diorite intrusion of the Massif du Nord and hence may be of very late Cretaceous age.

EARLIER BASALTIC ROCKS.

Distribution and Structural Relations.

Although the earlier basaltic rocks are widely distributed and their exposures cover considerable areas in some localities their structural relations are somewhat obscure, and the basement on which they rest was

not definitely recognized. As float of old schists is found on the surface of the volcanic rocks in the North Plain, it is believed that they originally rested on a basement of early Mesozoic or Paleozoic schists. (See p. 84.)

The old basalts are exposed on the North Plain at a number of places, and are found as float in the central and western parts. The northward-extending spurs and foothills of the Massif du Nord between Grande-Rivière du Nord and Les Perches are composed of volcanic rocks, at least a part of which are the older basalts. These hills, except for the northernmost extension of bedrock east of Le Trou, were not examined during the reconnaissance. Along the road from Cap-Haïtien to Ouanaminthe, about 6 kilometers east of Le Trou, these rocks crop out and are exposed intermittently from this locality eastward to the Fort Liberté road, a distance of about 10 kilometers. They are exposed in low ridges or flat domes that barely rise above the alluvial covering of the plain. At many places actual outcrops were not seen, although abundant float of angular joint blocks of the bedrock indicates that the covering of alluvium is thin. These exposures east of La Trou are cut by dikes and small stocks of quartz diorite porphyry.

Elsewhere in the eastern part of the North Plain these older volcanic rocks seem to have been largely engulfed in the quartz diorite and are now preserved only in small much metamorphosed patches. Small areas of the volcanic rocks were seen in the quartz diorite south of Les Perches, and small included fragments of both volcanic rocks and schists were noted at several places in the quartz diorite. (See Fig. 18, *B*, p. 311.)

Most of the amphibolitic and talcose schists at Morne Beckly were probably formed by intense dynamic and contact metamorphism of rocks of this series.

At Morne du Cap the altered basaltic rocks comprise a large part of the basement on which lies the upper Eocene limestone that caps the mountain. The basaltic rocks and some patches of Cretaceous (?) sedimentary rocks form the lower slopes and foothills of the Morne du Cap. The Cretaceous (?) cherts and sediments rest on the basaltic rocks, and certain conglomeratic beds in them contain pebbles derived from the basalts. Small bodies of quartz diorite porphyry are associated with the volcanic rocks here and presumably are intrusive into them.

Altered volcanic rocks, probably largely basalts, form a belt of low hills that extends southward from the igneous foothills of the Morne du Cap to the outlying hills of the Massif du Nord west of Milot. These volcanic rocks are intruded at a few places by small dikes or stocks of porphyry.

West of Grande-Rivière du Nord, and in Section Cormiers, where copper veins have been prospected, the country rock consists of basalts and some associated chloritic schists.

The igneous rocks of Limbé Mountain consist in part of much altered basaltic rocks of this series. The metamorphism of the rocks in this mountain is so intense that their exact classification is difficult. A large

part of Plaisance Mountain also is composed of altered volcanic rocks. The metamorphosed basaltic rocks crop out on the crest and north slope, but the south slope contains some younger andesitic and dacitic lavas. Intrusive stocks of quartz diorite, which probably caused much of the metamorphism, cut the older rocks and are exposed south of Limbé.

The basalts are exposed also at the base of the middle Eocene limestone in the small valley northeast of St.-Michel in Section Las Lomas. Here they are associated with chloritic schists exactly similar to those west of Grande-Rivière du Nord.

Associated with the basalts at many places there are ultrabasic rocks, such as peridotites and pyroxenites, and much-metamorphosed rocks, such as amphibolites and epidiorites. Some of these rocks may be intrusive into the basalts.

Petrography.

The earlier basaltic rocks are generally characterized by intense alteration and metamorphism. Most of them are greenish gray to dark green or nearly black, although some are reddish brown, purple, or gray. The green color in most of the rocks is due to secondary minerals, such as hornblende, epidote, and chlorite, and as a field designation most of the rocks could appropriately be called greenstones. Some of them are tough and fine-grained, and most of them are porphyritic or amygdular. The phenocrysts are generally altered plagioclase and augite and, more rarely, altered hypersthene or olivine. The amygdules are composed of chlorite, epidote, quartz, or zeolites. The rocks at some places are closely and irregularly jointed, and in road cuts and other outcrops they crumble away into small, irregular blocks. Some of the altered basalts are reddish brown or purplish gray. The weathered surface of the normal greenstones may be somewhat bleached to gray or brown.

The following types of rocks are the more common among the earlier basalts.

Olivine-free basalts.—Basalts of the olivine-free type, found west of Grande Rivière du Nord in Section Cormiers, on the North Plain, and in the vicinity of Limbé, are dark green to greenish gray and generally are porphyritic. Plagioclase when present as phenocrysts is generally found in clusters of prisms, 2 to 3 millimeters in diameter. So far as could be determined these basalts contain no alteration products derived from olivine. The groundmass is dense, and in thin section the texture is intergranular—that is, the rock consists of thin plagioclase laths, the largest about 0.1 millimeter in length, between which lie crowded small grains of augite. The plagioclase, both of the phenocrysts and groundmass, is dull megascopically and in thin section is invariably seen to be more or less completely altered to albite and clouded with alteration products. In some rocks the alteration products accompanying the albite can be recognized as epidote and zoisite.

The relatively unaltered augite is light greenish or yellowish and is more generally found unaltered than the plagioclase. In some rocks it is partly or completely replaced by chlorite or uralitic hornblende. Grains of magnetite between the plagioclase and augite are generally recrystallized in the altered rocks, some of them to tabular hematite.

A peculiar nonporphyritic basaltic rock of amygdular texture was found as a cobble in the Rivière Limbé, just south of the town of Limbé. The rock is purplish brown and contains amydules of white and greenish silicates, some as much as 4 centimeters in diameter. The texture is intergranular, the plagioclase laths, 0.05 to 0.10 millimeter in length, being surrounded with granules of augite about 0.05 millimeter in diameter. The somewhat dusty plagioclase has been recrystallized and consists largely of albite. The colorless or pale greenish augite is practically unaltered except for a small amount of secondary chlorite. The magnetite, a primary accessory, has been recrystallized in part to a platy ore, probably hematite, which in places cuts across the amydular fillings. The peculiar amygdules are bordered with albite, the centers consisting of blue-green and yellow-green minerals, possibly epidote.

The filling of the vesicles or replacement of the original amygdules with the albite and epidote (?) is clearly a result of the regional metamorphism of these basalts.

Hypersthene basalt.—At only one locality, in Section Cormiers west of Grande-Rivière du Nord, was hypersthene basalt found, but as it was found there associated with the ordinary basalts, basalts of this type may occur elsewhere. The rock is dark greenish gray, but weathers rusty brown. The plagioclase appears as clusters of phenocrysts and as thin laths in the groundmass largely altered to albite and clouded with prehnite, chlorite, and sericite. The hypersthene occurs as phenocrysts, which are now completely altered to a greenish pleochroic bastite. The augite in the groundmass is relatively fresh but has been in part altered to chlorite. The magnetite has been partly recrystallized. Chlorite and prehnite are present in amygdules and replace the plagioclase of the rock.

Other basaltic rocks.—Much-altered basaltic rocks containing numerous large phenocrysts of pyroxene were found on the North Plain. The constituents of these rocks are largely altered to amphiboles and to talc, so that there is some uncertainty as to the original character of the rocks. The porphyritic texture is not prominent on freshly broken surfaces, but on weathered surfaces the phenocrysts are etched out in relief, giving the rock a warty appearance. The pyroxene, which in some of the rocks is near diopside, is largely altered to a pale fibrous amphibole and chlorite, or to serpentine or talc. The secondary amphibole in many of these rocks is very pale and scarcely pleochroic. In some rocks talc is an important secondary constituent, having nearly completely replaced phenocrysts of diopside or forming part of the groundmass. A network of actinolitic

hornblende needles has replaced the pyroxene in some rocks along cleavage lines. In one specimen a few remnants probably of olivine were associated with flaky serpentine. Because of the abundance of large phenocrysts of pyroxene, many of the rocks are believed to be transitional toward the pyroxenites and peridotites. Extreme metamorphism and more complete recrystallization of basaltic rocks of this type may have produced the amphibolites and schists found at some localities on the North Plain. (See pp. 306-309.)

Alteration and Metamorphism.

These earlier basaltic rocks, which are at the base of the series of lavas, have been extensively intruded and partly engulfed in the quartz diorite batholith. This intrusion in Cretaceous or early Eocene time was probably the cause of their intense metamorphism, which is regional in extent. The most common alteration is the albitization of the calcic plagioclase, which is generally accompanied by the separation of epidote or uralitic hornblende. Albite and epidote were formed in some rocks without appreciable alteration of the augite. In more advanced metamorphism the albitization is accompanied by complete uralitization of the augite, and finally the rock is converted to an amphibolite. Some of the albite is altered along cleavage lines to sericite. Talc or serpentine may be important products of alteration in rocks consisting predominantly of pyroxenes.

At some localities, as near Grande-Rivière du Nord, the augite has been converted to chlorite and the conversion appears to be connected with the general metamorphism that accompanied the formation of the veins at that locality. Chlorite, calcite, and finally zeolites may more or less completely replace the plagioclase. Prehnite was noted as a replacement product of plagioclase and it forms amygdules in rocks from near Grande-Rivière du Nord. Epidote, chlorite, calcite, and zeolites are at many places found in amygdules, and zeolites encrust joint planes of an amphibolitized rock from Limbé Mountain.

ANDESITES AND DACITES.

Distribution and Structural Relations.

Andesitic and dacitic lavas are abundant in the northwestern part of the Massif du Nord and in the eastern and northeastern parts of the Montagnes de Terre-Neuve. Andesites are also found on the south slope of the Massif du Nord as far east as Lamielle. In general andesitic lavas appear to be the predominating type, although quartz-bearing rocks are widespread.

South of Plaisance Valley, at the foot of Mont Puilboreau, the dacites and andesites underlie the middle Eocene (Plaisance) limestone. (See Fig. 18, *C*, p. 311.) Near the foot of the mountain basal beds of the Plaisance limestone contain fragments of these lavas and also considerable

quartz, which appears to have been derived from dacitic lavas outcropping near by. Just below the conglomeratic beds, at an altitude of about 530 meters, a yellowish much altered dacitic lava, with included blocks of dark, fresher dacite is exposed. A kilometer or so farther down the slope, near the foot of the mountain, at an altitude of about 420 meters, there are exposures of altered pyroxene andesites. Faulting in the volcanic rocks obscures their original relative positions, although the position of the dacites close to the middle Eocene conglomerate indicates that the dacites were at or near the top of the volcanic series and probably overlie the andesites. The alteration of both the dacites and andesites gives evidence of intrusive activity, although no intrusive rocks are exposed at the surface.

Andesites and dacites were found north of Dondon and in the valley of Grande-Gille, which runs from a locality just east of the Citadelle northeastward to the valley of the Grande Rivière du Nord. Conglomeratic and tuffaceous beds in marine Cretaceous(?) argillites, about 3 kilometers north of Dondon (see p. 88), contain abundant angular fragments of altered dacitic lava and of quartz and plagioclase. The abundance of quartz in the argillite indicates that quartz-bearing lavas were surface rocks during its deposition. Homogeneous tuffaceous-appearing material in a calcareous matrix containing small Foraminifera may indicate some contemporaneous eruptions during the deposition of the argillite, although rapid transportation or reworking of older tuffs might under certain conditions give similar results. No actual flows of volcanic rock were found in any part of the argillite series.

The prevailing volcanic rocks along the trail southward from Milot to the Citadelle of Christophe and Dondon are pyroxene andesites.

Small areas of hornblende and pyroxene andesites were found in the northwestern part of the Montagnes Noires. A small interior valley along the Rivière Coupe-à-l'Inde and back of the first limestone range east of Dessalines is floored in part with hornblende andesites. Southeast of Gonaïves pyroxene andesites, olivine-bearing andesite, and basaltic rocks are exposed along the mountain front and in the valleys east of Morne Grammont. Small patches of much altered hornblende andesites are associated with the Cretaceous(?) argillites exposed in the valley back of the first limestone range of the Montagnes Noires southwest of St.-Michel. Locally the andesites seem to have buried or intruded the Cretaceous(?) rocks. The alteration of the andesites appears to be due to intrusive bodies of dacite porphyry. The lavas in the Montagnes Noires are exposed in lowlands or valleys formed by removal of the upper Eocene limestone.

Andesites and dacites constitute a considerable proportion of the lavas in the mountains between Gros-Morne and Le Borgne. At some places in this region the lavas are altered, apparently owing to the proximity of underlying intrusive bodies of quartz diorite.

The distribution of the andesites in the Montagnes de Terre-Neuve is discussed in the description of the Terre-Neuve district. (See p. 430.)

Hornblende andesite was seen at one locality northeast of Gonaïves, along the railroad track to Ennery, in a cut near Kilometer 16. Here the hornblende andesite has been thrust up along a high-angle fault into contact with the overlying basaltic rocks. (See Pl. XVIII, *A*, p. 280.)

Hornblende-mica andesite or dacite porphyries crop out southwest of Jean Rabel and are apparently intruded by the quartz diorite porphyry. They are bright reddish rocks showing in some places a conspicuous flow structure. The structural relations of these rocks are somewhat obscure, but owing to their texture and the apparent intrusive relations of the quartz diorite porphyry they are tentatively correlated with the effusive andesites and dacites.

Andesitic and dacitic appearing lavas were noted in the agglomeratic material underlying the upper Eocene (?) limestone on Morne Chien, northwest of Baie de Henne.

Petrography and Chemical Composition.

Pyroxene (augite-hypersthene) andesites.—The rocks called pyroxene andesites are fine grained to dense or glassy and are prevailing porphyritic in texture; amygdular types are rare. In general the fresher glassy or partly glassy lavas are black to green or greenish gray; the more crystalline and more altered lavas are reddish, purplish brown, or gray. Oxidation by weathering and by circulating solutions has changed the lavas locally to red ferric oxide tints. A mottling of green and reddish tints is found in some places. Weathering bleaches the dark-green lavas to brown or gray speckled with whitish feldspar phenocrysts.

Most lavas of this group contain some glass; lavas that are predominantly glassy or predominantly holocrystalline are not so abundant as intermediate types. Phenocrysts of both plagioclase and pyroxene are generally present in the lavas. The plagioclase phenocrysts reach a length of 5 millimeters in some lavas, but their average length is between 1 and 2 millimeters. Greenish-black augite and in some lavas yellowish-brown grains of hypersthene can be recognized.

In thin sections the plagioclase is in euhedral to subhedral laths that range in length from 0.2 to 4 or 5 millimeters and comprise about 15 per cent of the volume of the rock, though their sizes and proportions differ in different lavas. The crystals are zoned and show Carlsbad, albite, and in some specimens penetration twinning. Extinction angles on combined twins and indices of refraction show that the plagioclase has a composition around Ab_{40} An_{60}.[1] Strongly zonal phenocrysts range from bytownite (Ab_{30} An_{70}) to sodic labradorite (Ab_{50} An_{50}). Both augite and hypersthene generally are present in varying proportions and together

[1] Wright, F. E., A graphical plot for use in the microscopic determination of the plagioclase feldspars: Am. Jour. Sci., 4th ser., vol. 36, pp. 540-542, 1913.

constitute from 6 to 10 per cent of the rock. The hypersthene occurs in prisms, the largest of which are 1 to 2 millimeters in length, and the mineral has a distinct but faint pleochroism, which ranges from pale yellowish to gray-green. In the lavas that contain a considerable proportion of glass in the groundmass the hypersthene is practically unaltered. As the groundmass becomes predominantly crystalline most of the hypersthene is altered to bastite, which may be accompanied by calcite and by various forms of silica. A second generation of hypersthene, occurring as microlites, invariably altered to bastite, is found in places in the groundmass of the more crystalline lavas.

The augite is in light-greenish or greenish-gray prisms, from 0.5 to 2 millimeters in length, that show no pleochroism. The angle $Z \wedge c$ is about 46°. In the more glassy lavas it is unaltered, but in the more crystalline lavas it is here and there partly altered to calcite or quartz. It generally occurs in larger crystals than the hypersthene. The groundmass usually has a characteristic andesitic or hyalopilitic texture, consisting of a felted aggregate of plagioclase microlites in an interstitial light-brown glass base. In specimens in which the base is more crystalline small prisms and quadratic sections of plagioclase may predominate. The plagioclase microlites are generally 0.05 millimeter or less in size and vary in composition from oligoclase to sodic labradorite in different specimens. Small grains and specks of magnetite are attached to the plagioclase microlites. Apatite in thin needles is here and there an accessory mineral. Reddish-brown flakes of hematite are present in some specimens. The subordinate glass base usually has an index of refraction of 1.50 to 1.52.

Holocrystalline pyroxene andesites are not abundant, although they may be more common than the specimens collected would indicate. In general they seem to have been confined to the hornblende-bearing types. A few specimens of holocrystalline pyroxene andesites were found, but they are somewhat altered, so that the original character of the plagioclase could not be determined. The hypersthene is altered to bastite or other alteration products, and the augite in one specimen partly to calcite, plagioclase, quartz, and iron oxides. The groundmass of such rocks is a fine-grained irregular intergrowth of plagioclase grains and prisms.

Pyroxene andesites, consisting predominantly of glass, were found on Morne Dumuraille in the Montagnes de Terre-Neuve, in the vicinity of Morne Macat, in the valley of the Rivière Lhormand west of Gros-Morne, and northeast of Gros-Morne. Most of the very glassy rocks have a sheeted or platy structure, caused probably by contraction due to sudden cooling after they were extruded. Plagioclase and pyroxene phenocrysts can be recognized with the unaided eye and range from a fraction of a millimeter to 1 or 2 millimeters in length. The augite is in greenish-black grains and the hypersthene, where unaltered, is in somewhat smaller yellowish-brown grains.

The plagioclase in these glassy lavas generally ranges in composition from bytownite (Ab_{25} An_{75}) to sodic labradorite (Ab_{50} An_{50}). In some specimens magnetite is rather abundant in octahedral grains, the largest half a millimeter in diameter. The index of refraction of the glass base generally is about 1.50 to 1.52. The glass base of some lavas has perlitic texture. (See Pl. XXII, *B*, p. 304.) In other features the lavas are like the more crystalline ones and are presumably of similar composition.

A chemical analysis of a glassy pyroxene andesite from Morne Dumuraille, commune of Terre-Neuve (Pl. XXII, *B*), is given below. This analysis, as well as those of other rocks in this report, was made by Dr. H. S. Washington of the Geophysical Laboratory, Carnegie Institution of Washington. This analysis, its calculation as water-free, and the average of some analyses of andesites for comparison are given in the following table:

Chemical analysis of pyroxene andesite from Morne Dumuraille and average analyses of andesites.

	1	1-a	2	3
SiO_2	61.41	64.23	60.35	59.92
Al_2O_3	14.00	14.65	17.54	17.51
Fe_2O_3	2.56	2.68	3.37	2.98
FeO	2.69	2.81	3.17	3.70
MgO	3.01	3.15	2.78	3.31
CaO	5.29	5.53	5.87	6.66
Na_2O	3.39	3.55	3.63	3.44
K_2O	1.56	1.63	2.07	1.65
H_2O+	3.93	....	....	....
H_2O-	0.55	....	....	....
TiO_2	1.17	1.22	.78	.48
P_2O_5	0.37	0.39	.26	.20
MnO	0.14	0.15	.18	.15
	100.07			

1. Pyroxene andesite, south slope of Morne Dumuraille, commune of Terre-Neuve, Republic of Haiti. H. S. Washington, analyst.

1-a. Analysis 1 calculated as water free.

2. Average of 87 analyses of all andesites (calculated as water free). Daly, R. A. Igneous rocks and their origin, p. 26, 1914.

3. Average of 20 analyses of hypersthene andesites calculated as water free. Daly, R. A., op. cit., p. 26, 1921.

The norm of the rock, calculated from this analysis according to the system of *quantitative classification*,[1] is as follows:

Norm of pyroxene andesite from Morne Dumuraille.

Quartz	21.60	Hypersthene	6.61
Orthoclase	9.29	Magnetite	3.71
Albite	28.72	Ilmenite	2.24
Anorthite	18.24	Apatite	.91
Diopside	4.43	The rock is tonalose ("II.4.3.4).	

[1] See Washington, H. S., Chemical analyses of igneous rocks: U. S. Geol. Survey Prof. Paper 99, appendix 1, pp. 1151-1180, 1917.

In its relatively low alumina and high titanium the andesite corresponds to quartz diorite of Cretaceous age (p. 292) and to the granodiorite of Miocene (?) age (p. 304). The silica is also higher than in the average andesites given by Daly. As there is little secondary alteration the high proportion of water in the lava is noteworthy.

Hypersthene andesites.—Lavas containing predominant hypersthene or hypersthene alone as the ferromagnesian constituent are apparently less abundant than the augite-hypersthene type. A dark brownish-gray glassy hypersthene andesite was found along the trail between Gros-Morne and Pilate. In a dark-gray andesite from middle or upper Eocene conglomeratic beds at Morne Macat, hypersthene is the predominant ferromagnesian mineral. Except for the absence or the low proportion of augite these lavas are similar to the glassy pyroxene andesites.

Augite-hypersthene-hornblende andesite.—Andesite containing hornblende in addition to augite and hypersthene was found only at Dolan, southwest of Terre-Neuve village. This rock is holocrystalline, partly altered, and mottled reddish brown to green. The plagioclase phenocrysts range in composition from calcic labradorite (Ab_{35} An_{65}) to sodic labradorite or andesine. Augite crystals together with bastite pseudomorphs after hypersthene form 10 or 15 per cent of the rock. The hornblende, generally largely resorbed to an opaque aggregate containing iron oxides, has a pleochroism from yellow to reddish brown, probably due to a high proportion of ferric iron. The groundmass is plagioclase, largely andesine, and some magnetite and secondary iron oxides. Secondary quartz and chrysocolla are present as the result of alteration adjacent to mineralized fissures.

Hornblende-augite andesites.—Lavas of the type known as hornblende-augite andesites were found at several places, although alteration and weathering makes most of the specimens unsuitable for petrographic study. The unweathered and unaltered rocks are generally gray, but the weathered or altered rocks may be reddish or rusty brown. They are usually speckled with rusty brown needles of hornblende, which have been largely resorbed.

A comparatively fresh rock from a locality in the valley of the Rivière Coup à-l'Inde, a tributary of the Estère, just east of Dessalines, is representative of these lavas. It is a gray rock speckled with small altered needles of hornblende and whitish prisms of partly kaolinized plagioclase from 1 to 2 millimeters in length. The plagioclase phenocrysts occur in rather stout prisms, in part fragmental, and comprise about 15 to 20 per cent of the rock. They are zoned but not so markedly as in the pyroxene andesites, ranging from medium andesine to a sodic oligoclase at the margins of crystals. Their average composition is probably around Ab_{65} An_{35} to Ab_{60} An_{40}. Iron oxides and scattered flakes of kaolinite are alteration products. The hornblende needles comprise 5 to 8 per cent of the

rock and are largely resorbed, although a few remnants of a reddish-brown hornblende remain. There are scattered prisms of a fresh colorless to pale-greenish augite. The groundmass is apparently largely oligoclase but is clouded with specks of iron oxides and contains some chlorite. The plagioclase is in thin needles and stouter anhedral plates, which show no well-defined arrangement.

Hornblende andesites.—The lavas known as hornblende andesites are generally light gray or greenish gray where fresh, but where oxidized and altered may be reddish or rusty brown. Many of the reddish lavas in the Montagnes de Terre-Neuve are probably altered hornblende andesites. The freshest andesite was obtained along the Gonaïves-Ennery railroad in a cut near Kilometer 16. The rock is light gray and carries phenocrysts of plagioclase and thin needles of hornblende 1 to 2 millimeters in length. The plagioclase phenocrysts range in composition from calcic andesine to labradorite and comprise about 10 per cent of the rock. The hornblende has a thin resorption rim, probably consisting of iron oxides and augite, and is pleochroic from faint yellow to yellowish or brownish green. It comprises 5 to 8 per cent of the rock. The groundmass contains some glassy base and consists of a plexus of thin, needle-like prisms and larger quadratic and irregular sections, chiefly andesine. There is some quartz in the groundmass, mostly in small nests of anhedral grains. Octahedral grains of magnetite and stout prisms of apatite are accessories.

Hornblende-mica andesites or dacites.—Rocks of the type of hornblende-mica andesites or dacites were found southwest of Jean Rabel. They are conspicuously porphyritic, and some specimens have a prominent flow structure. They are purplish and contain large whitish phenocrysts of plagioclase, from 1 to 6 millimeters in length. Hornblende occurs generally in small, inconspicuous needles, although some are 2 to 3 millimeters in length. There are a few scattered flakes of biotite. The phenocrysts of plagioclase are zonal and range from labradorite (Ab_{45} An_{65}) to andesine, probably averaging around Ab_{50} An_{50} to Ab_{45} An_{55}. They comprise 15 to 20 per cent of the rock. A few corroded and fragmental crystals of quartz show transition toward dacite. The hornblende is deep brown, and the smaller needles are generally resorbed to iron oxides and augite. The biotite, like the hornblende, is partly resorbed to magnetite. The groundmass, like that in the other hornblende andesites, consists of andesine and contains a few scattered grains of primary augite. Magnetite and stout prisms of brownish apatite are the usual accessories. Opalescent silica, a secondary mineral, obscures the structure of the groundmass and is probably formed by weathering.

Pyroxene (augite-hypersthene) dacites.—Pyroxene dacites were found at the north base of Mont Puilboreau and in the region north of Gros-Morne and Pilate. These rocks are greenish gray to gray where dense and relatively fresh, but many of them, either from oxidation or from alteration show dull shades of red or purple. The green or gray lavas are por-

phyritic, with phenocrysts of plagioclase ranging from 0.5 to 5 millimeters in length and crystals of augite and hypersthene, both of which are commonly altered. Quartz is present in rounded bipyramidal crystals, some of them 5 to 6 millimeters in diameter. In most of the specimens studied the plagioclase had been altered by the Cretaceous quartz diorite intrusion to albite and sericite; in one relatively fresh rock it consisted of sodic andesine (Ab_{65} An_{35}). Except for the phenocrysts of quartz and for some quartz in the groundmass the rocks are much like the pyroxene andesites in general textural features and accessory minerals.

Hornblende-augite dacites.—Lavas of the type known as hornblende-augite dacites were found in the Montagnes de Terre-Neuve north of Terre-Neuve village. They are purplish gray and contain prisms of whitish feldspar from 1 to 2 millimeters in length, scattered crystals of quartz, and dull-brown needles of hornblende that are largely resorbed. The phenocrysts of plagioclase are near andesine (Ab_{60} An_{40}), and the groundmass consists of sodic andesine in thin prisms with a trachytic texture. There are scattered crystals of augite partly replaced by calcite.

Hornblende-mica dacites.—The hornblende-mica andesites near Jean Rabel contain some quartz, and some varieties are dacites. Hornblende-mica dacite porphyry was found in the Montagnes Noires, but because of its coarse porphyritic character and the accompanying alteration it probably does not belong to the andesite-dacite effusive group, and it is discussed under the heading "Intrusive rocks." (See p. 299.)

Relations of the Various Types.

The variation in the mineral composition and texture of the lavas of this group covers a rather wide range. The almost continuous gradations between the various types indicate their close relationship and their common origin. The pyroxene and hypersthene andesites constitute the more basic members of this group; the hornblende andesites and the dacites the more salic members. Pyroxenes are found, however, in some of the dacitic lavas, and some hornblende also occurs in the more basic andesites. Conditions such as the percentage of water or variations in pressure or in temperature probably controlled the crystallization of hornblende and pyroxene from the magmas. In the rocks nearest the salic end of the group, the hornblende-mica andesites or dacites, the pyroxenes are subordinate or absent, and the alteration of these more salic rocks as a whole indicates greater activity of the water in their magmas. The universal resorption of hornblende to augite and iron oxides probably is the result of extrusion or intrusion to positions of reduced pressure, where the escape of water vapor rendered the hornblende unstable. In certain altered hornblende-mica andesites near Jean Rabel small crystals and microlites of pyroxene crystallized in the groundmass, though hornblende was the stable mineral during the early or intratelluric period of crystallization.

Alteration and Metamorphism.

The principal widespread alterations in this group of lavas are the alteration of hypersthene, resorption of hornblende, and some replacements of the constituents by secondary forms of silica, chlorite, serpentine, and probably hematite and other iron oxides. The hypersthene commonly alters to bastite or other forms of serpentine, which may be accompanied by quartz, chalcedony, or opal. These alterations are all apparently related to events occurring during the extrusion of the lavas, such as the action of expelled magmatic waters, or to the action of associated hot springs. More intense forms of local metamorphism, as albitization and sericitization of the plagioclase, replacement of augite by aggregates of calcite, quartz, plagioclase and iron oxides, and more complete chloritization, are the results of circulating solutions genetically related to the quartz diorite intrusion.

LATER BASALTIC ROCKS.

Distribution and Structural Relations.

Basaltic lavas that are younger than the andesites and dacites previously described appear to be confined to a zone which extends from the vicinity of Ennery northwestward at least as far as the village of Gros-Morne and which includes parts of the Montagnes de Terre-Neuve. This zone is rather indefinitely bounded, both because of the lack of information and because the lavas are covered by the Tertiary limestones.

Lavas of this group are exposed at a number of places along the Gonaïves-St.-Michel road southeast of Ennery. They are found under the upper Eocene limestone and fragments of them occur as cobbles or pebbles in conglomeratic beds near its base. Outcrops of the lavas at many places in this vicinity show pillow structure. Other exposures of these basalts underlying the upper Eocene limestone were seen at the southern base of Mont Puilboreau along the Plaisance-Ennery road.

Northeast of Gonaïves, approximately south of Morne Deux Mamelles, these basalts crop out both along the automobile road to Ennery and along the Gonaïves-Ennery railroad. At Kilometer 16 on the railroad a cut shows a fault contact between the basaltic rocks of this series and the underlying hornblende andesites. (See Pl. XVIII, *A*.) The andesite has been thrust up into contact with the basalt. The fault strikes about N. 50° E. and dips 57° SE. The basalt is amygdular and shows pillow structure. A reddish shaly limestone containing many small Foraminifera fills the interstices between the rounded to subangular pillows of basalt. The evidence indicates that the basalt had intruded or flowed over beds of unconsolidated calcareous deposits. Essexite belonging to this group of rocks crops out about half a kilometer northeast of Poteau. It probably underlies the Eocene limestone unconformably. The texture

A. THRUST FAULT IN RAILROAD CUT SOUTH OF MORNE DEUX MAMELLES, NORTHEAST OF GONAÏVES.

Andesite (at left) is thrust over younger basalt (at right).

B. BEDDED VOLCANIC DÉBRIS ON SAVANE MADAME MICHAUD SOUTHEAST OF SAUT D'EAU.

of this rock indicates that it may belong to a minor intrusive body of this series.

Lavas petrographically similar to those in the vicinity of Ennery occur in the Montagnes de Terre-Neuve. Particularly fresh diabasic and amygdular rocks are exposed along the trail from Gros-Morne to Terre-Neuve on the northeast slope of Morne Découflay. Some of the rocks at this locality have a coarse diabasic texture with ophitic plates of augite 8 or 10 centimeters in diameter and may be parts of minor intrusive bodies. Abundant float of this type of basalt is found along the valley of the Rivière Lhormand, part of which may come from the western part of Section Moulin. The basaltic rocks in the valley of the Rivière Bras-à-Droit are of the Ennery type, and at one place they seemed to form an intrusive sheet parallel to the bedding of the Eocene limestone. As there were no inclusions of the limestone in the basalt and as the relations could be explained by strike faulting, this exposure is not considered as conclusive evidence of the Eocene or post-Eocene age of the basalt at this locality.

Along the trail from Gros-Morne to Pilate, 2 or 3 kilometers east of Gros-Morne, these later basalts are exposed near reddish-brown shaly limestones of unknown age.

Although the region was not explored, rocks of this group will probably be found in the area of igneous rocks on the east side of the trough of the valley of Les Trois Rivières from Morne Deux Mamelles northwestward to Gros-Morne.

Petrography.

General features.—This later series of basaltic lavas and intrusive rocks has some distinctive features which sharply separate them petrographically from the earlier basaltic rocks. They are characterized by a purplish titaniferous augite that commonly shows a tendency toward idiomorphic development, in contrast to the interstitial pale-greenish augite or diopside of the ordinary basalts; some of the more alkaline rocks are further characterized by sodic plagioclase, anorthoclase, and analcite or other soda zeolites.

In chemical composition the magmas ranged from essexite to nearly normal olivine diabase. All the types probably have a high content of titanium, but no chemical analyses are available to determine the extent of the variation in the amount of this constituent from that in ordinary basaltic rocks.

No primary sodalite or nephelite was identified in any of the rocks, but much of the clear analcite, if it is secondary, has probably replaced these minerals, as its relations in many places indicate that it is not a replacement of primary plagioclase. In some rocks intense zeolitization has resulted probably from the local circulation of highly alkaline solutions of extraneous origin caused by the general volcanic activity.

Essexite.—Rock here classified as essexite was found at only one locality, about half a kilometer northeast of Poteau along the road from Gonaïves to Ennery, at the base of a small hill west of the road. Because of its relatively coarse diabasic texture this rock has been classified as essexite, although its field relations do not show whether or not it is part of an intrusive body.

The essexite is a medium-grained greenish-gray rock of diabasic texture in which prisms and grains of dark augite and of greenish plagioclase can be recognized with the unaided eye. The rock is spotted with pinkish glassy patches of analcite 2 to 3 millimeters in diameter.

In thin section the texture generally is hypidiomorphic but locally may be typically ophitic. The earlier plagioclase is labradorite (Ab_{45} An_{55}), but the crystals are very strongly zoned and most of these have borders of oligoclase or of albite. The albite is distinguished by its low refractive index and positive optical character. The average plagioclase of the rock is at least as sodic as andesine. Potash feldspar forms irregular borders surrounding the plagioclase, or occurs in clear interstitial patches between the plagioclase and augite, or borders miarolitic cavities which are filled with analcite and zeolites. The potash feldspar in some places shows idiomorphic outline against analcite in miarolitic cavities. The orthoclase probably is soda orthoclase, as the indices are higher than those for normal potash orthoclase ($\alpha = \pm 1.523$; $\gamma = \pm 1.53$), and the optic angle (2 V) is medium to small. The proportion of soda orthoclase or anorthoclase is difficult to estimate because of its alteration and the presence of albite, but the ratio of orthoclase to plagioclase appears to lie between one-fifth and one-third. The pyroxene is a purplish-brown pleochroic augite, commonly somewhat zonal, and is found mostly in hypidiomorphic prisms with cross fractures and with the margins molded on the more calcic plagioclase. A few of the crystals are more idiomorphic, but some of the augite fills the angular spaces between the plagioclase in a typical ophitic manner. The maximum extinction angle of the zonal augite on 010 is 53°, and the pleochroism is from yellowish gray to purplish brown. The crystals are generally from 1 to 2 millimeters in length. The analcite is interstitial and fills the angular spaces between the feldspars and between the plagioclase and augite, or else it occurs in aggregates, some of which show crystal outline in miarolitic cavities in the rock. Analcite also replaces the plagioclase along some of the cleavage cracks, and such analcite is undoubtedly secondary. Ilmenite, which is usually in peculiar skeletal growths, is quite common in grains from microscopic size up to 0.4 or 0.5 millimeter in diameter, and some of it is included in the augite. Some titaniferous magnetite may be present. Long fractured needles of a nearly colorless or slightly greenish apatite are very abundant as inclusions in the alkali and plagioclase feldspars but are less common in the augite. Small shreds of a dark-brown strongly pleochroic biotite are

present. Both the feldspar and the augite are replaced along cracks by chlorite. Calcite occurs in spherulitic or radial growths, some of them molded on the analcite crystals, and fills many of the cavities in the rock.

The mineral composition of the rock was calculated approximately by the Rosiwal method as follows:

Mineral composition of essexite from locality near Poteau.

	Percentage by volume.
Feldspar	50.0
Augite	27.0
Analcite	15.0
Iron-ores	8.0
Biotite and apatite	0.5

The percentage of soda orthoclase in the rock could not be conveniently measured but was estimated at 8 to 12 per cent. The strongly zonal plagioclase probably averages at least as sodic as andesine in composition. The rock has some affinities with rocks which have been described as analcite monzonites, although in the relative proportions of the alkali feldspar and the plagioclase it is more comparable to the granodiorites among the quartz-bearing rocks. Johannsen, in his mineralogical classification,[1] has suggested the name monzodiorite for rocks of this character, and in this classification the rock would be an analcite monzodiorite with the symbol 2224.

Analcite andesites and analcite-olivine andesites.—The analcite andesites and analcite-olivine andesites are dark-gray to greenish-gray rocks where unweathered, but where they are at the surface they may be a rusty or greenish brown. Their field relations do not definitely show whether these rocks are parts of thick flows or of intrusive bodies. They are generally spotted with growths of natrolite or other zeolites. Fine-grained rocks of this type were found north of Ennery near the base of Mont Puilboreau and in the valley of the Rivière Bras-à-Droit north of Terre-Neuve.

The plagioclase is strongly zonal and ranges in composition from labradorite to sodic oligoclase or albite. Because of the irregular borders of sodic plagioclase the interlacing prisms are never strictly euhedral. Between the plagioclase laths a small amount of soda orthoclase is found in some of the specimens, but it is inconspicuous. The plagioclase generally amounts to 40 or 50 per cent of the rock. The purple pleochroic augite occurs in subordinate amount, forming 20 to 30 per cent of the rock, and is exceedingly variable in its development. It may form subhedral to euhedral prisms, which are commonly hollow or skeletal, or it may occur in anhedral grains interstitial to the plagioclase. Olivine apparently

[1] Johannsen, A., A quantitative mineralogical classification of igneous rocks—revised: Jour. Geol., vol. 28, pp. 50, 175, 177, 1920.

was a primary constituent in some of the rocks but is completely altered to serpentine in all those examined. The serpentine has migrated to some extent and is accompanied by chloritic minerals. In some specimens analcite and in others natrolite or other zeolites fill angular spaces between the plagioclase, and all the zeolites replace the feldspars to a variable extent. In one specimen analcite forms scattered round grains. The iron ore is probably largely ilmenite and forms peculiar skeletal grains, but much of it shows no alteration. Some of it is accompanied by small flakes of biotite. Small microlites of a greenish mineral, probably augite, are abundant in some specimens. All the rocks contain some calcite.

These rocks clearly are transitional between the essexite and the more normal basalts described below. As the average plagioclase is andesine and the ferromagnesian minerals are subordinate, the rocks can not be classified as basalts or tephrites, although they have some of the structural characteristics of the normal basaltic rocks of this group.

Amygdaloidal basalts.—Conspicuous amygdaloidal basalts were found along the road between Ennery and St.-Michel, where they underlie the upper Eocene limestone. The amygdules generally consist of chlorite, calcite, or zeolites. The rocks are normally dark greenish gray but may be stained brown by weathering.

One of these rocks from a locality about 3 kilometers southeast of Ennery is nonporphyritic in thin section and has a type of intergranular texture. The prisms of plagioclase and augite are from 0.2 to 0.5 millimeter in length, and the amygdules, which comprise about 20 per cent of the volume of the rock, are from 1 to 3 millimeters in diameter. The plagioclase is labradorite and slightly zonal, ranging from Ab_{35} An_{65} to Ab_{45} An_{55}. The augite is purplish brown and zonal, with "hour-glass" structure, and has an extinction on 010 that ranges from 46° to 52°. Some of the augite occurs in irregular grains interstitial to the plagioclase and some forms thin nearly euhedral prisms, in places grown parallel to the plagioclase. The iron ores occur in part in skeletal growths and are presumably titaniferous. Chlorite is abundant in the rocks and is either interstitial to the plagioclase and augite or fills or lines the vesicles. Augite is the predominating constituent of the rock and forms 40 to 50 per cent of the groundmass; chlorite makes up 12 to 15 per cent of the rock exclusive of that in the amygdules. Both calcite and zeolites form fillings in the amygdules.

Zeolitized olivine basalts and diabases.—Olivine-bearing basaltic rocks, which are nearly normal basalts although they still show some affinities to the more alkaline members of this group, were found in the Montagnes de Terre-Neuve. They are dark greenish gray and contain prisms of plagioclase 1 to 2 millimeters long, a few yellowish grains of olivine, and large plates of pyroxene. Some of the rocks are speckled with white radial growths of zeolites, mostly natrolite. The plagioclase is only slightly

zonal, ranging from bytownite (Ab_{15} An_{85}) to basic labradorite, and is in euhedral to subhedral laths from 0.5 to 2 millimeters in length. It comprises approximately 40 per cent of the rock. The augite is brownish gray, and some of it has a distinct purplish tinge, but it is not so strongly tinted as that in the more alkaline rocks. The extinction on 010 is about 45°. In places it forms large plates, 4 to 6 millimeters in diameter, which are poikilitic and inclose prisms of plagioclase. The olivine occurs in rounded and partly or completely serpentinized granules, which range in diameter from 0.5 to 2 millimeters, and comprises from 5 to 10 per cent of the rock. Some of the olivine wraps partly around the end of the prisms of plagioclase like the augite. The principal accessory mineral is magnetite in irregular skeletal or octahedral grains, amounting to about 5 per cent. Thin needles of apatite, a few prisms of green and brown hornblende, and a few flakes of biotite partly altered to chlorite are minor accessories.

The serpentine is a greenish flaky nonpleochroic variety and replaces plagioclase adjacent to the olivine along with some chloritic minerals. Analcite has replaced the basic plagioclase along cracks to some extent, and zeolites, mostly natrolite, are present as fibrous radial growths between the laths of plagioclase. A small amount of calcite is generally associated with the zeolites. The zeolites and subordinate analcite may constitute from 5 to 10 per cent of the rock.

Olivine diabase.—The type classified as olivine diabase is similar to the preceding rocks in texture and mineral composition, but the rock contains little or no analcite and only a few scattered growths of natrolite. It was found on the east slope of Morne Découflay, along the trail between Gros-Morne and Terre-Neuve. Its coarse texture and position indicates that it may bear intrusive relations to the pyroxene andesites. (See Fig. 27, section *A-A'*; p. 442.)

Alteration.

The principal alterations are the formation of zeolites, chlorite, serpentine, and calcite. These rocks show no recognizable alterations that could be attributed to the Cretaceous regional metamorphism. The above-mentioned secondary minerals can all be attributed either to later magmatic (deuteric) replacements, or to the action of circulating alkaline solutions associated with the vulcanism. As indicated by the sodic plagioclase and soda orthoclase among the later minerals of crystallization of some of the rocks, there was a considerable concentration of alkaline constituents in the residual magmatic liquids, which resulted in the formation of analcite and natrolite. Some of the rocks have probably been enriched by soda derived from alkaline solutions of extraneous origin.

Chlorite and serpentine generally appear to have been formed before zeolite or calcite. Chlorite fills pores in the rocks and in many lavas lines vesicles that are filled with later calcite or zeolite.

Relations of the Various Types.

Because of the close association of the members of this series in their distribution, and because they show certain distinctive mineralogic features, they are believed to constitute a cogenetic group that is entirely separate from the older andesites and dacites. The distinct gradations that occur between the alkaline and the normal basaltic members of this group indicate genetic relations. In the group as a whole the order of crystallization of the essential minerals is generally olivine, bytownite and labradorite, titaniferous augite, sodic plagioclase, soda orthoclase, analcite, and natrolite. Sodic plagioclase and small amounts of orthoclase found in rocks where crystallization begins with olivine and labradorite furnish sufficient proof that the rocks of this group are closely related and that olivine diabase magma was the parent magma of this group. The decided tendency of the magma toward an alkaline descent is apparent even in the more basic members of the group. The strong zoning of the plagioclase and possibly a low percentage of water and the presence of carbon dioxide in the magma should be considered as contributing to this descent. Calcite occurs in all the rocks and appears to have been deposited from the solutions that deposited zeolites, although at a somewhat later stage. The surface lavas contain blowholes, many of which are filled with calcite.

Age of the Lavas.

At most places these rocks seem to be older than the middle and upper Eocene limestones, and probably they are younger than most of the pyroxene and hornblende andesites. This would place their period of eruption some time between early Cretaceous and middle Eocene. At several places they are associated with shaly calcareous sediments of unknown age, and at some places they have intruded or flowed over unconsolidated calcareous muds. So far as known they were not intruded or altered by the late Cretaceous batholithic intrusion. They are therefore probably of early Eocene or late Cretaceous age.

Intrusive Rocks.

General features and distribution.

Igneous intrusives, which represent at least three periods of intrusion, can be recognized in the northern part of the Republic. Little is known of the earliest period, evidences of which remain only in much metamorphosed intrusives associated with the older basalts. Most of the rocks of this group were basic types intruded probably during or soon after the earlier periods of basaltic eruptions. The most important period of intrusive activity is represented by the quartz diorite intrusions. These batholithic rocks, which are probably of late Cretaceous age, intrude the

older Mesozoic volcanic rocks and the older schists. The intrusion and the preceding and accompanying folding resulted in widespread regional metamorphism. The latest known intrusions are represented by minor stocks of quartz diorite or granodiorite of Miocene (?) age. Minor intrusive bodies that accompanied the various volcanic eruptions have been mentioned in the description of the volcanic rocks.

The largest area of intrusive rocks is exposed in the eastern part of the Massif du Nord, where the core of the quartz diorite batholith has been exposed by erosion. West of Grande-Rivière du Nord the quartz diorite is exposed only in smaller stocks or bosses. The oldest intrusive rocks associated with the metamorphosed volcanic rocks and amphibolites were not differentiated in the field. The youngest intrusions are in the Montagnes de Terre-Neuve and occupy only a narrow zone. Small bodies of porphyry, probably in part of intrusive origin, are exposed in the Montagnes Noires.

EARLIER BASIC INTRUSIVES.

Distribution and Structural Relations.

In the field no attempt could be made to separate the earlier basic intrusive rocks from the older volcanic rocks, as their character and relations are obscured by extreme metamorphism.

No large bodies of intrusive rock of this group were recognized. Minor intrusive bodies of composition similar to that of the extrusive basaltic rocks and minor bodies of basic differentiates, such as peridotites and pyroxenites, probably constitute most of the bodies of rock that make up this group. Altered gabbros, epidiorites, and peridotites or pyroxenites, which are described from the Province of Santiago in the Dominican Republic,[1] may represent part of these old basic intrusives. The serpentine that covers large areas in the Cordillera Central of the Dominican Republic may represent altered peridotites, pyroxenites, or gabbros.

Much altered and relatively coarse grained diabasic rocks, the structural relations of which are unknown, were found on Limbé Mountain and between Limbé and Plaisance. Float of similar rocks was found on the Plaine du Nord. Much-metamorphosed basaltic rocks and float of augite peridotite were found in the Valley of Las Lomas. Many of the highly metamorphosed rocks—the amphibolites, talc schists, and epidosites—were derived by alteration from basic or ultrabasic rocks, some of which may have been parts of minor intrusive bodies.

Petrography.

A number of the rocks of these older igneous groups could not be definitely classified because of advanced metamorphism. They consist chiefly of uralitic hornblende and some dusty albite feldspar, generally

[1] A geological reconnaissance of the Dominion Republic: Dominican Republic Geol. Survey Memoirs, vol. 1, pp. 84-85, 1921.

with some chlorite, epidote, and quartz. Some of the commoner types of the rocks showing more advanced metamorphism are described on pages 306-309.

Metadiabase.—Rocks that have probably resulted from the metamorphism of relatively coarse diabasic rocks were found on the Plaine du Nord and in the mountains near Limbé and north of Plaisance. These rocks are dark green to greenish gray and of rather uniform texture. They may be stained rusty brown by weathering. One of these rocks, from a locality near the crest of Limbé Mountain, shows in thin section traces of an ophitic or diabasic texture in less altered parts. The plagioclase consists largely of dull-brown or dusty albite crowded with flakes of sericite and microlites of the alteration products of the rocks, pale-green hornblende, chlorite, and epidote. Remnants of primary augite show an extinction angle on 010 of about 45°, although the crystals are largely replaced by uralitic hornblende. The secondary hornblende is faintly pleochroic, from yellowish or nearly colorless to a faint green or blue green with the angle $Z \wedge c$ about 16° or 17°. The amount of uralitic hornblende and augite somewhat exceeds the amount of plagioclase. Chlorite is found as an alteration product parallel to the cleavage lines of the hornblende. The iron ores are partly recrystallized and are coated with grains of titanite.

A rock probably of similar origin found on the North Plain contains more epidote and quartz. In some of the specimens the sodic plagioclase is partly altered to sericite.

Augite peridotite.—Although peridotite was found only in the Valley of Las Lomas, rocks of this type are believed to be generally distributed in minor quantities throughout the older series. Peridotites are reported from the basal complex of the Dominican Republic, as well as from Cuba, and are the natural basic differentiates of the basaltic magmas of these early periods of igneous activity.

The augite peridotite is a greenish-black rock of medium grain composed of augite and other ferromagnesian minerals and minor quantities of greenish plagioclase. In thin section the rock is seen to be composed predominantly of olivine in anhedral to subhedral crystals, which form 60 to 70 per cent of it. It alters with the characteristic mesh structure to serpentine and iron oxides. The augite is brownish yellow, unaltered, and generally interstitial to the olivine crystals. Some of the larger plates of augite inclose small subhedral olivine crystals in a poikilitic manner. An orthorhombic pyroxene in small cross-fractured prisms and grains with faint pleochroism, from nearly colorless to pale yellowish, is a minor accessory. Plagioclase, probably bytownite, is an interstitial constituent and is in part altered to opaque brownish saussuritic patches and to serpentine derived from the olivine. It constitutes about 10 per cent of the rock. The other accessories are grains of iron ore and flakes of a pale altered biotite.

EARLIER QUARTZ DIORITE GROUP.

Distribution and Structural Relations.

The rocks of the earlier quartz diorite group are most widely distributed in the eastern part of the Massif du Nord, where the batholith of quartz diorite is exposed by erosion over an area of 500 to 650 square kilometers. Small stocks and apophysal dikes are exposed on the Plaine du Nord. The rocks of this group clearly are intruded into the Mesozoic volcanic rocks and schists, but whether they are intrusive into the sedimentary rocks of supposed Lower Cretaceous age on the southern border of the Massif du Nord is not known. During the reconnaissance no intrusive contact between these rocks was found. A locality between Bahon and Ranquite,[1] where they presumably are in contact, was not visited. Evidence discussed on page 299 indicates, however, that the quartz diorite is younger than the Lower Cretaceous rocks.

About 12 or 15 kilometers east of Le Trou the volcanic rocks are intruded and metamorphosed by small stocks or dikes of quartz diorite porphyry, and abundant float of the intrusive rocks is found on the surface of the volcanic rocks. On Morne Beckly dikes of porphyry and felsite, which probably belong to this intrusive group, cut the schists. Veins of quartz carrying sulphides or iron oxides and pegmatitic veins have been considerably deformed.

West of the Grande Rivière du Nord the intrusive rocks are exposed only in small stocks or dikes cutting the metamorphosed volcanics. Such bodies were seen on Morne du Cap north and west of Cap-Haïtien and on the North Plain along the road from Cap-Haïtien to Limbé.

About 6 or 7 kilometers north of the town of Grande-Rivière du Nord, near the railroad station called La Tannerie and west of the river, there is an exposure of a kaolinized porphyry in contact with fossiliferous limestone of late upper Cretaceous age. (See pp. 94-95.) The relations at this locality suggest faulting, and the limestone shows no evidence of contact metamorphism, but the relations of the quartz diorite to these Upper Cretaceous limestones are not known.

South of Limbé, on the road to Plaisance, there are several exposures of quartz diorite. The surrounding older volcanic rocks are strongly metamorphosed. Farther west evidence of intrusive bodies was established by the finding of float boulders of quartz diorite in Section Margot, along the trail from Port Margot to Pilate.

Exposures of quartz diorite porphyry, presumably related to this intrusive group, were found in the Northwest Peninsula at several places in the Commune of Jean Rabel. The largest exposures examined are 7 or 8 kilometers southwest of the town of Jean Rabel, along the valley of the

[1] Tippenhauer, L. G., Beiträge zur Geologie Haïtis: Petermanns Mitteilungen, vol. 47, map opposite page 198, 1901.

Rivière Cadet. The rocks are apparently intrusive into hornblende-mica andesites at this locality and are overlain unconformably by limestone of upper Eocene age. Cobbles of quartz diorite and of the porphyries are found in the basal upper Eocene conglomerate along the valley of the river. Near the crest of the mountains along the trail from Jean Rabel to Anse Rouge quartz diorite porphyry underlies the upper Eocene limestone.

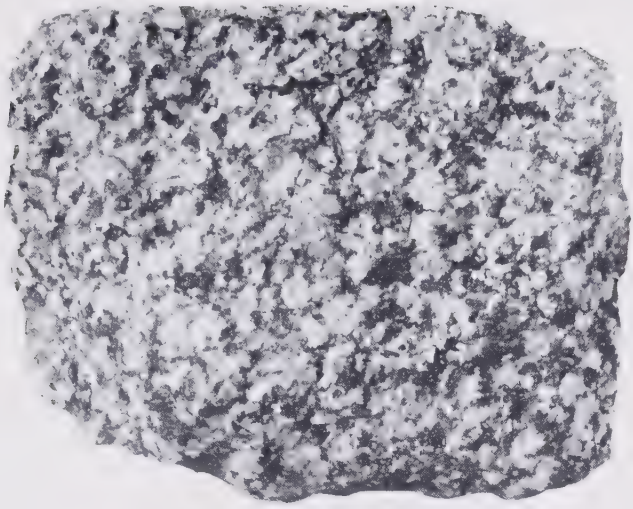
Petrography and Chemical Composition of the Normal Quartz Diorite.

The normal quartz diorite, the dominant type of this intrusive group, is a speckled gray to greenish-gray medium to coarse grained granitoid rock. (See Pl. XIX, *A*.) The constituents recognizable with the unaided eye are prisms of whitish plagioclase showing albite twinning lamellae, greenish-black hornblende, generally subordinate to the light constituents, and abundant quartz, usually in grains interstitial to the plagioclase and hornblende. A little magnetite and some chlorite can be distinguished, and in altered rocks some secondary pyrite and epidote. The rocks are generally rather even grained in texture, and the plagioclase is here and there idiomorphic. The distinctly porphyritic rocks, which are less abundant, contain phenocrysts of plagioclase, the largest of them 1 centimeter in length, which stand out prominently as white blotches on the weathered surface. (See Pl. XIX, *B*.) One rock was found in which large poikilitic plates of hornblende, 8 to 10 millimeters in diameter, inclose some of the smaller prisms of plagioclase.

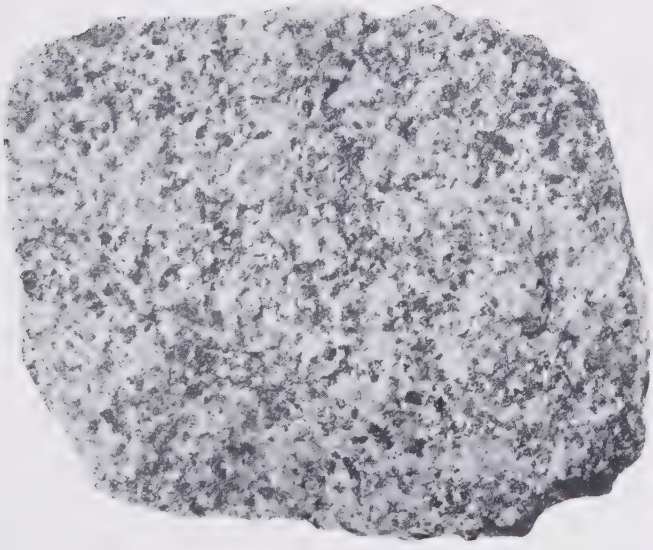
Along narrow zones the quartz diorite has been intensely sheared, although no general gneissoid texture was found. Some of the rock shows evidence of intense dynamic strain that has crushed the quartz and plagioclase and drawn out the hornblende. In some of these crushed rocks the quartz is distinctly bluish. Quartz diorite gneiss that apparently belongs to this group of intrusives has been found in the Dominican Republic[1] in the Cordillera Central, a continuation of the Massif du Nord of the Republic of Haiti.

In thin section the plagioclase shows a euhedral tendency and generally seems to have been the first mineral to crystallize except a few small grains of accessory minerals. (See Pl. XXI, *A*.) The prisms are subhedral to euhedral and are generally 1 to 4 millimeters long. The outside rims of the smaller crystals show growth interference with the larger crystals of hornblende and with a few of the crystals of quartz. The plagioclase shows Carlsbad and albite twinning, is zonal, and ranges in composition from calcic andesine or sodic labradorite in the centers of prisms to sodic andesine or oligoclase on the borders (Ab_{45} An_{55} to

[1] A geological reconnaissance of the Dominican Republic: Dominican Republic Geol. Survey Mem., vol. 1, pp. 84, 202, 1921.



A. QUARTZ DIORITE FROM MORNE MADELINE, SOUTH OF LES PERCHES.



B. PORPHYRITIC QUARTZ DIORITE FROM MORNE MADELINE, SOUTH OF LES PERCHES.

Ab_{70} An_{30}). Its average composition is probably around Ab_{60} An_{40}. Most of it is slightly altered to gray saussuritic patches, in some specimens zonally developed, and small grains of colorless zoisite or clinozoisite. Some sericite generally occurs along the cleavage lines. The quartz occurs in irregular grains from 1 to 3 millimeters in diameter, interstitial to the other constituents of the rock. It is irregularly cracked and has a wavy extinction. Small bubbles containing gaseous and liquid inclusions are common along the cracks in the quartz.

The hornblende is in subhedral prisms, generally 1 to 3 millimeters in length, less commonly 5 to 6 millimeters, or in irregular grains of smaller size molded on the more calcic plagioclase. The earliest hornblende generally is interstitial to the larger prisms of plagioclase, but the period of crystallization of the hornblende overlaps that of the plagioclase and to some extent that of the quartz. The hornblende ranges in color in different specimens of rock, or even in the same specimen, from colorless to olive-green, blue-green, or brown-green. Colorless hornblende in a coarse porphyritic rock from Morne Madeleine, south of Les Perches, has a border of light olive-green. The colorless variety was of slightly lower refraction and somewhat higher double refraction than the green variety, but both varieties had about the same extinction angle ($Z \wedge c = 19°$ to $20°$).

Magnetite is present in octahedral or irregular grains generally associated with or inclosed in hornblende or chlorite. Small prisms of colorless apatite inclosed in plagioclase and a few grains of titanite are found in most of the rocks. A few minute crystals of zircon were noted in some slides. Chlorite (penninite) is a secondary mineral that is everywhere present, either replacing hornblende or in separate flakes, and is in places interlaminated by opaque streaks of fine granular epidote or epidote and calcite. Possibly some of the chlorite may be secondary after biotite. Biotite altering to chlorite was found in a porphyritic phase of the intrusive rock in the Northwest Peninsula. Biotite is reported to be subordinate to hornblende in specimens of quartz diorite from the Cordillera Central in the Dominican Republic.[1] Orthoclase is usually absent in sections of the typical quartz diorite.

One rather unusual type of quartz diorite was found near the chapel on Savane Longue, on the trail from Mont Organisé to Ouanaminthe. In this rock large poikilitic plates of hornblende inclose small prisms of plagioclase and crystals of magnetite. The hornblende is more abundant than that in most of the quartz diorite and constitutes about 28 per cent of the rock by volume. The quartz also forms large grains, which include and wrap around the plagioclase in a poikilitic manner. (See the following table, specimen No. 3.) The plagioclase ranges from Ab_{55} An_{45} to Ab_{40} An_{60} and the average is probably a calcic andesine.

[1] Op. cit., p. 84.

The approximate mineral composition of several thin sections of quartz diorite as determined by the Rosiwal method is as follows:

Approximate volumetric mineral composition of quartz diorite.[a]

	1	2	3
Quartz	34.0	27.6	22.4
Andesine[b]	51.3	43.3	41.0
Hornblende	12.0	24.0	28.0
Magnetite	1.2	2.1	2.7
Chlorite	1.5[c]	3.0[c]	4.2
Epidote	....	....	1.2
Titanite	Trace	Trace	0.5

[a] See also p. 495 for mineral composition and physical properties of quartz diorite tested for road-building material.

[b] Includes 2 to 3 per cent of sericite. [c] Includes some epidote.

1. Specimen from Rivière Marion, near Acul Samedi. Field No. K 185 L. (See Pl. XIX, *B*.)
2. Specimen from Morne Madeleine, south of Les Perches. Field No. K 186 L.
3. Specimen from Savane Longue between Mont Organisé and Ouanaminthe. Field No. W 342 L.

The chemical composition of a specimen of quartz diorite collected on the north slope of Morne Madeleine, along the trail between Les Perches and Vallière, is shown in the following table, which contains also one hitherto unpublished analysis of quartz diorite from the Virgin Islands and the average of twenty analyses of quartz diorite for comparison.

Analyses of quartz diorite from Morne Madeleine and quartz diorite from Virgin Islands, and average analysis of quartz diorite.

	1	2	3
Al_2O_3	13.33	16.47	16.52
SiO_2	59.66	61.22	59.47
Fe_2O_3	5.12	2.97	2.63
FeO	5.53	3.47	4.11
MgO	4.50	2.54	3.75
CaO	5.96	6.18	6.24
Na_2O	3.14	3.81	2.98
K_2O	0.97	1.77	1.93
H_2O+	0.47	1.12	1.39
H_2O-	0.08	0.19	
TiO_2	1.55	0.48	0.64
P_2O_5	0.18	None	0.26
MnO	0.12	0.13	0.08
	100.61	100.45[a]	

[a] BaO, 0.04; SrO, 0.06.

1. Quartz diorite, north slope of Morne Madeleine, between Les Perches and Vallière, Republic of Haiti. H. S. Washington, analyst.
2. Quartz diorite, Virgin Islands, Island of Vieques, western edge of Mosquito. R. C. Wells, analyst; T. W. Vaughan, collector.
3. Average of 20 analyses of quartz diorite. Daly, R. A., Igneous rocks and their origin, p. 26, 1914.

The approximate mineral composition of the analyzed specimen, estimated from determinations by the Rosiwal method and from chemical calculations, and the norm calculated according to the quantitative classification are given in the following table:

Approximate mineral composition and norm of quartz diorite from Morne Madeleine.

Approximate mineral composition.		Norm.	
Quartz	23.0	Quartz	18.89
Andesine (Ab_{60} An_{40} ±)	[a]46.0	Orthoclase	5.95
Hornblende	23.6	Albite	26.62
Magnetite	4.7	Anorthite	19.12
Chlorite	[b]2.7	Diopside	7.57
		Hypersthene	11.10
		Magnetite	7.47
		Ilmenite	2.97
		Apatite	0.34
		The rock is tonalose (II.4.3.4").	

[a] Includes sericite amounting to 2 to 3 per cent of the total. [b] Including some epidote.

The high percentage of quartz in these rocks and the negligible percentage or lack of potash feldspar are striking. In the specimen analyzed no potash feldspar was found on the slide, although very small amounts may have escaped detection. The chemical analysis shows, however, that the rock is unusually low in potassium oxide, even for rocks in the quartz diorite family. All or nearly all of the potassium is probably in the plagioclase. The high content of titanium and the low content of alumina are the only other notable features of the chemical analysis. Ferric iron possibly replaces alumina in some of its combinations.

Minor Variations.

Minor quantities of the rocks of this group range from seemingly basic appearing types, in which the hornblende may constitute 35 to 40 per cent of the rock, to types in which the dark minerals may constitute 15 per cent or less. Most of these rocks are, however, probably classifiable as quartz diorite, although the more basic members are transitional toward quartz-hornblende gabbro, and the more acidic members are oligoclase quartz diorites or transitional toward granodiorites. The structural and age relations of these different types are unknown.

Quartz diorite.—Rocks in which the plagioclase is strongly zonal, generally ranging from calcic andesine (Ab_{50} An_{50}) to sodic oligoclase and albite, were found south of Limbé. The borders of oligoclase and albite are irregular, so that although zoning gives the plagioclase an appearance of euhedrism it is largely in subhedral to anhedral crystals. The albite may form irregular patches interstitial to the plagioclase. The plagioclase in these rocks generally is considerably altered to sericite, to saussuritic

patches, and to epidote, probably owing to the position of the rocks near intrusive contacts at this locality.

Ophitic quartz diorite.—A fine-grained phase of the intrusive was found about 4 kilometers northeast of Mont-Organizé. It is a gray-speckled rather even textured rock that contains a very few scattered ill-defined phenocrysts of plagioclase. In thin section the texture is ophitic, the thin euhedral plagioclase laths being inclosed in grains of later crystallized hornblende and quartz. The plagioclase, which occurs in thin laths from 0.5 to 1 millimeter in length, with only a few twinning lamellae, ranges in composition from sodic labradorite (Ab_{50} $An_{50}\pm$) to andesine (Ab_{65} An_{35}). The more massive hornblende is brown-green and incloses the plagioclase laths like augite plates in typical diabase. In addition a secondary blue-green hornblende in shreddy prisms cuts across the structure of the rock. The quartz also is in grains inclosing the plagioclase and is an abundant constituent, forming 25 per cent or more of the rock. Magnetite, chlorite, epidote, and titanite are found in the rock. The plagioclase is partly clouded with saussurite and sericite. In mineral composition the rock apparently corresponds closely to the normal quartz diorite, of which it appears to be a textural variety.

Dacite pophyries.—Fine-grained contact porphyries were found near the southern border of the batholith north of Lamielle. They are greenish-gray porphyritic rocks with phenocrysts of plagioclase, hornblende, and quartz in a fine-grained groundmass. In one section studied the subhedral plagioclase phenocrysts are strongly zoned and range in composition from sodic bytownite to calcic andesine. The quartz occurs in somewhat corroded bipyramidal crystals. The hornblende is a pale-green fibrous variety, partly altering to chlorite and epidote. The groundmass consists of a fine-grained granulitic growth of andesine and quartz in which the quartz apparently occurs in somewhat subordinate amounts. Rather large octahedral grains of magnetite are commonly associated with the hornblende.

Kaolinized porphyry.—A kaolinized porphyry with large phenocrysts of quartz, some of which are 4 or 5 millimeters in diameter, was collected north of the town of Grande-Rivière du Nord, near the railroad station called La Tannerie. The phenocrysts of plagioclase have been completely replaced by kaolinite, and the groundmass has recrystallized to an aggregate of quartz, kaolinite, and some sodic plagioclase. The rock contains abundant pyrite, which apparently accompanied the introduction of the kaolinite and quartz.

Quartz diorite porphyries.—A greenish-gray quartz diorite porphyry of medium grain crops out about 10 kilometers south of Jean Rabel. It is part of the basement under the upper Eocene limestone. In thin section the texture is porphyritic, with euhedral to subhedral prisms of plagioclase and hornblende, from 1 to 5 millimeters in length, and corroded bipyramidal crystals of quartz, the largest of them 2 millimeters in

diameter, in a fine-grained groundmass. The phenocrysts comprise about 50 per cent of the volume of the rock. The plagioclase ranges in composition from andesine to sodic oligoclase and probably averages a sodic andesine (Ab_{70} An_{30} to Ab_{65} An_{35}). The hornblende is in long twinned pale-olive or blue-green prisms and comprises about 20 per cent of the rock. The groundmass of the rock consists of a fine intergrowth of sodic plagioclase, quartz, and some orthoclase, although the proportions of the constituents are difficult to determine. Titanite is an abundant accessory or secondary mineral. It accompanies the hornblende and occurs also in the groundmass. The orthoclase in these porphyries is much more abundant than in the quartz diorites exposed farther west in the Massif du Nord.

Rocks like the porphyries just described but in which the plagioclase is more sodic, probably averaging oligoclase in composition, were found southwest of Jean Rabel. Much of the porphyry here is pyritized.

The pale-green color and shreddy appearance of the hornblende in these rocks from the Northwest Peninsula and the grains of titanite included in and associated with it suggest that it has been formed by recrystallization of a primary hornblende with the accompanying separation of titanite. These porphyries are intrusive into hornblende-mica andesites, which possibly accounts for their texture and alteration.

Dike Rocks and Veins.

General features.—Most of the dike rocks that are definitely correlated with the quartz diorite are those which cut the main body of the batholith itself in the Massif du Nord. A small number of dikes and veins of doubtful origin on the Plaine du Nord cut the schists and metamorphosed volcanic rocks but are believed to be genetically related to the rocks of the quartz diorite group.

Fine-grained to aphanitic dikes a few meters across cut the batholith at several places. Some of them are extremely altered flinty rocks carrying considerable pyrite and other alteration products. A section of one from a locality north of Les Perches shows a microcrystalline growth of secondary amphibole, chlorite, and magnetite, probably some quartz, and a few nests of coarser grained plagioclase, chlorite, or hornblende. The rock shows evidence of considerable brecciation.

A somewhat coarser grained dike of this type from the Rivière Marion near Acul Samedi contains about 60 per cent of hornblende in euhedral but somewhat fibrous prisms, 0.2 to 1.0 millimeter long, in a groundmass of plagioclase and quartz. The hornblende, a blue-green variety, apparently has been somewhat recrystallized. The plagioclase is labradorite and commonly shows micrographic intergrowth with quartz or occurs in sheaf-like groupings. There is about 20 per cent of quartz in the rock. Magnetite, epidote, and chlorite are present. The rock is considerably

richer in the ferromagnesian minerals than any of the quartz diorites and is probably related to the lamprophyres.

Dikes of porphyry and felsite at Morne Beckly are extremely altered. A porphyritic dike containing phenocrysts of plagioclase and quartz has been largely recrystallized. The plagioclase was recrystallized to albite with the separation of epidote. The original character of the rock can not be determined.

Large veins of pure quartz cut the quartz diorite and the surrounding rocks. The mineral-bearing veins related to this intrusion are described on pages 459-468. Veins of hornblende and of hornblende and quartz, sharp or blurred, cut the batholith along shear zones and joints. A quartz hornblendite of this type from Morne Madeleine consists of hornblende, 50 to 60 per cent; quartz, 25 to 35 per cent; magnetite, 5 per cent; and chlorite and epidote, 8 to 10 per cent. The hornblende is massive and pleochroic in colors ranging from yellowish to brownish green. The quartz grains are full of dustlike inclusions and give wavy extinction. The rock contains some titanite, which is associated with the chlorite and epidote, and a few grains of zircon. These hornblendite veins, as shown by their mineral composition, are the later products of crystallization of the quartz diorite magma and presumably comprise a differentiate that has been transported outward from the zone of crystallization by aqueous solutions.

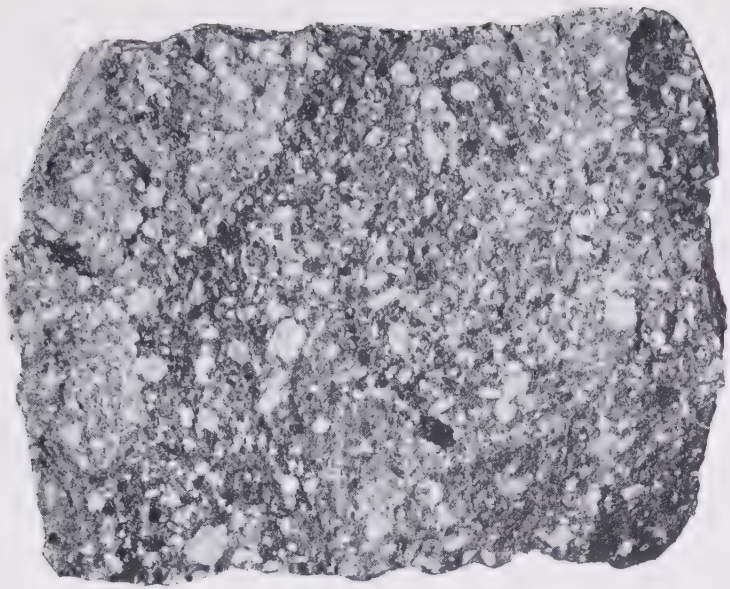
Alteration and Metamorphism.

Both the contact phases of the intrusive itself and the invaded country rocks for a considerable distance from the intrusive contact are intensely altered and metamorphosed. Enormous quantities of highly alkaline aqueous solutions must have escaped from the solidifying magma, in places even at considerable depths and pressures.

Alteration in the contact phases of the intrusive itself consisted in some recrystallization of the hornblende, accompanied by separation of titanite and iron oxides, and albitization and sericitization of the plagioclase. The epidote and calcite in the plagioclase and the quartz and epidote veinlets that cut the quartz diorite itself were probably formed during this period of alteration. Locally pyrite was developed abundantly in the contact porphyries and accompanies quartz and kaolinite along later shear veins.

The quartz veins carrying copper sulphides and iron oxides are later phases of the intrusive activity and are described in greater detail on pages 459-468.

The deep-seated metamorphism of the basic eruptive rocks next to the quartz diorite contacts was very intense and generally resulted in the development of amphibolites or of rocks consisting essentially of amphiboles and varying amounts of albite. Epidote, quartz, chlorite, sericite, and iron oxides are other products of the metamorphism. Where intense



A. DACITE PORPHYRY FROM SAVANE LA CIDRA, MONTAGNES NOIRES.

B. GRANODIORITE FROM MEMÉ VALLEY, COMMUNE OF TERRE-NEUVE.

shearing action has accompanied the intrusion hornblende, chlorite, and talc schists have been formed.

The lines of schistosity developed in some of the schists clearly antedate some of the later quartz veins of the intrusion, showing that intense deformation was in progress before the intrusive period and during its earlier part. Some pegmatite veins intruded along the schistosity have a pinch and swell structure. The most intensely metamorphosed rocks were generally found near the outcrops of quartz diorite, and where intrusive bodies were not seen the quartz or pegmatite veins and intrusive dikes indicate the presence of larger intrusive bodies near by or concealed beneath the surface.

At greater distances from the contacts albitization is not generally accompanied by the change of the pyroxenes to amphiboles, although some epidote is formed. The formation of chlorite from augite took place at some localities. In a few andesitic rocks orthoclase had partly replaced secondary albite. Rarely the augite in some of the less intensely altered andesites or dacites was partly recrystallized to a granular aggregate of calcite, plagioclase, iron oxides, and quartz.

Prehnite was found near Grande-Rivière and Lamielle as an alteration product of plagioclase and filling cavities in much altered andesitic rocks. Zeolites are found occasionally under similar circumstances, and at one place they were found along joint planes in an amphibolitized rock. Probably these minerals represent a very late stage in the intrusive period, when the temperature of the rocks and of the aqueous solutions had fallen considerably.

Although the distance from the intrusive contacts to which the more intense metamorphism reached can not be estimated because of the possibility of concealed or undiscovered intrusive bodies, partly amphibolitized and albitized rocks were found from 2 to 4 kilometers from any known surface exposures of the quartz diorite. Rocks in which albite had been formed but in which the augite was left relatively unaltered were found from 6 to 7 kilometers from known exposures of the intrusive mass. Rocks found in place in the eastern part of the Montagnes de Terre-Neuve, probably from 15 to 20 kilometers from any outcrop of quartz diorite of this age, show no alteration attributable to the intrusion. This area and small areas of volcanic rocks in the extreme western part of the Northwest Peninsula and possibly in the northwestern parts of the Montagnes Noires are the only ones in the northern part of the country where older rocks are unaffected by this intrusion.

Weathering.

In exposures of the quartz diorite that are not subjected to active erosion weathering has decomposed the rock to considerable depths. Excellent exposures of a section through the residual soil were found at the

crest of the trail between Les Perches and Vallière on Morne Madeleine. The upland at this locality stands about 600 meters above sea level. It is rolling and has a relief of about 100 meters. Remnants of flat surfaces possibly represent an older Tertiary erosion surface which had been partly peneplained. The surface of this upland is covered, except where erosion is active, with a thick mantle of clayey soil derived from the quartz diorite bedrock.

The upper 4 or 5 meters of the soil has a mottled appearance and is of a reddish color. It consists essentially of a mixture of clay, earthy hematite and limonite, brown earthy manganese oxides, and undecomposed fragments of quartz. At a depth of a few meters the clay is spotted with white blotches of nearly pure kaolinite, some of which are stained a delicate pink, probably by manganese oxides. A sample of the kaolinite was picked and separated from included quartz fragments and was analyzed with the following results:

Analysis of kaolinite from residual soil on quartz diorite at Morne Madeleine.[1]

SiO_2	44.88
Al_2O_3	41.03
Fe_2O_3	.27
Mn_2O_3	Trace.
H_2O below 110° C.	1.40
H_2O above 110° C.	12.70

The analysis as well as the optical properties indicate that the material probably is kaolinite, which is derived from the plagioclase by alteration. The earthy brown to black manganese oxides, which form veins and irregular pockets in the upper part of the residual clay, are derived from the hornblende by decomposition. The upper reddish clayey soil grades down through the speckled clay to partly decomposed quartz diorite and to solid rock. The concentration of the manganese in the upper part of the soil is very noticeable but not in such quantities as to form commercial deposits at any place. A description of a section through weathered quartz diorite gravel and sand containing large concretions of iron and manganese oxides is given on pages 477-478.

Between Lamielle and Mont Organisé a red clayey soil similar to that on Morne Madeleine is found on the weathered surface of the quartz diorite. The red clay is very conspicuous at Mont Organisé.

At the northern part of the North Plain, in the vicinity of Les Perches, small pockets of white clay, probably largely kaolinite, were seen along the slopes of the ravines. They probably were concentrated by water in favorable places during Pleistocene or Recent time.

[1] Analyst, Earl V. Shannon, United States National Museum. Material for analysis examined optically and pronounced homogeneous by E. S. Larsen, of the United States Geological Survey.

The kaolinization of the plagioclase is noticeable on weathered exposures of the quartz diorite, particularly in porphyritic phases of the rock, where the phenocrysts are attacked first so as to give the rock a spotted appearance.

Age of Intrusion.

The intrusion of quartz diorite probably occurred between the end of Lower Cretaceous and the beginning of middle Eocene time. Although the quartz diorite is not definitely known to intrude the Lower Cretaceous argillite series, the presence of large and small quartz veins cutting these argillites between Cerca-la-Source and Lamielle and the metamorphism of the argillites indicate that the quartz diorite is younger. In the Dominican Republic, along the edge of the pre-Tertiary basal complex south of Sabaneta and between Sabaneta and Restauración, sericitic argillites that probably are of the same age as the argillites of the Republic of Haiti are intruded by quartz diorite and dikes of granitic or dioritic porphyry.[1] Although the argillite south of Sabaneta is somewhat more metamorphosed than most of the Cretaceous (?) rocks in the Republic of Haiti, it resembles, according to the Dominican report,[2] sheared slaty argillites south of Restauración that are without doubt a continuation of the band of Cretaceous (?) rocks extending southeastward from Lamielle.

The relation of the quartz diorite to the late Upper Cretaceous limestones found only in the region around Grande-Rivière du Nord is not known—a relation that if determined would place the age of the intrusion within narrow limits.

The quartz diorite porphyries in the Montagnes de Jean Rabel are overlain unconformably by the upper Eocene limestone, and pebbles of a porphyry presumably related to the quartz diorite in origin are found in the basal upper Eocene conglomerate on Morne du Cap. Dacites much altered by the intrusion are unconformably overlain by relatively unaltered Plaisance limestone (middle Eocene) at the northeast base of Mont Puilboreau. No effects of contact metamorphism have been found in any of the Tertiary limestones.

The quartz diorite is therefore probably of late Cretaceous age, as before Eocene time at least the outer shell of the batholith had been exposed by erosion near what is now the Montagnes de Jean Rabel.

DACITE PORPHYRY OF THE MONTAGNES NOIRES.

Distribution and Structural Relations.

A dacite porphyry is exposed southwest of St.-Michel, in the intermontane valleys of the northwestern part of the Montagnes Noires. This rock constitutes the greater part of the igneous rocks in the valley in Savane

[1] A geological reconnaissance of the Dominican Republic: Dominican Republic Geol. Survey Mem., vol. 1, pp. 52, 53, 56, 1921.

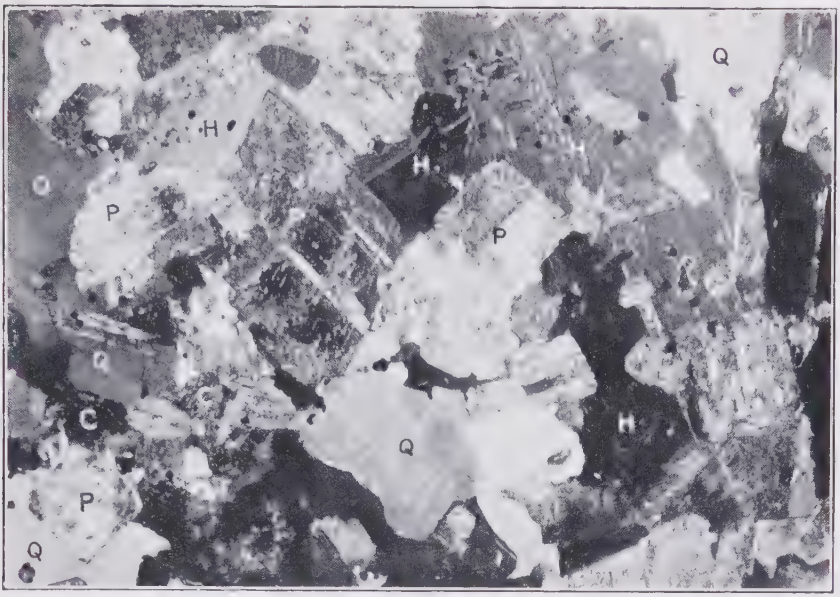
[2] Op. cit., pp. 52-53.

la Cidra back of the first limestone range southwest of St.-Michel and part of the rocks flooring the second savanna, in which stands the village of Paul. These savannas are separated by limestone ranges. In Savane la Cidra the dacite porphyry is in contact with hornblende andesites and sedimentary rocks of supposed lower Cretaceous age. The Cretaceous (?) rocks are mildly contact metamorphosed near the porphyry, as shown by a development of epidote, chlorite, quartz, and in places cubes of pyrite. The andesites have been altered to greenish-gray rocks containing abundant secondary epidote, quartz, chlorite, and calcite, and in some specimens the plagioclase is altered to albite and sericite. In the dacite porphyry itself there is some recrystallization of the hornblende, sericitization of the plagioclase, and formation of a manganese epidote from the ferromagnesian minerals. At some places farther southwest in the savanna the dacite porphyry shows a well-developed flow structure and evidence of brecciation. There is a lack of definite structural evidence to demonstrate either the intrusive or extrusive origin of the porphyry, although its texture and the accompanying metamorphism indicate that part of the porphyry exposed belongs to minor intrusive bodies. As the Cretaceous (?) beds presumably were the surface formation in early Tertiary or late Cretaceous times, the intrusive bodies probably were rather close to the surface, which may account for the texture and widespread resorption of the hornblende in the porphyry. The porphyry may, however, have broken through the comparatively thin cover of Cretaceous (?) deposits in some places.

Petrography.

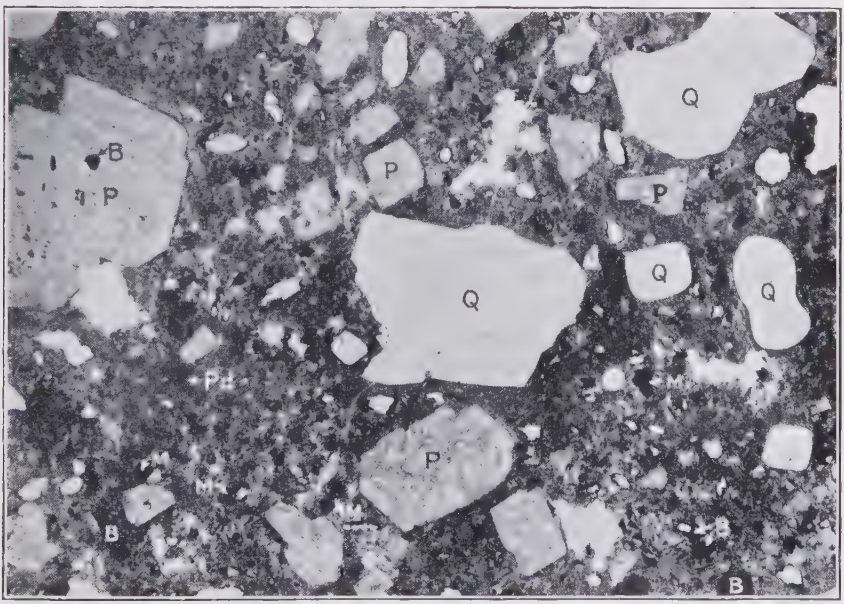
The dacite porphyry is a conspicuous purplish-gray to brown rock with large crystals of plagioclase, prisms of hornblende, grains of quartz, and scattered hexagonal plates of dark mica in a felsitic groundmass. (See Pl. XX, *A*, and Pl. XXI, *B*.) The porphyry bleaches somewhat in weathering and gives rise to a soil that in favorable places contains residual concretionary masses of iron and manganese oxides very much like those found on the quartz diorite soil northeast of Acul Samedi. (See pp. 477-478.)

In thin section the plagioclase phenocrysts are seen in zoned euhedral or fragmental prisms, ranging in composition from calcic andesine to oligoclase (Ab_{50} An_{50} to Ab_{70} An_{30}). Carlsbad and albite twinning are common. The prisms range in size from less than a millimeter up to 5 millimeters and constitute roughly 20 per cent of the rock volume. The hornblende is in euhedral to subhedral prisms as much as 5 millimeters in length and in small scattered grains comprising 8 to 10 per cent of the rock. It is a basaltic variety, is pleochroic from yellowish to deep brown, and is partly resorbed, leaving an aggregate of magnetite and augite. The quartz is in irregular grains or rounded crystals as much as 5 or 6 millimeters in diameter. It is somewhat shattered but gives sharp extinction.



A. PHOTOMICROGRAPH OF QUARTZ DIORITE FROM MORNE MADELINE, SOUTH OF LES PERCHES.

P, plagioclase, partly sericitized; Q, quartz; H, hornblende; C, chlorite. Crossed nicols, ×10.



B. PHOTOMICROGRAPH OF DACITE PORPHYRY FROM SAVANE LA CIDRA, MONTAGNES NOIRES.

Q, quartz; P, plagioclase; B, biotite; M, magnetite; Pd, piedmontite. Ordinary light, ×10.

The mica is a deep-brown pleochroic variety, with high birefringence and unusually high refraction, and possibly contains some manganese ($\beta =$ 1.7±, 2V medium to small, $a =$ straw yellow, $\gamma =$ deep brown). It is usually resorbed around the borders of flakes and is partly altered to a manganese epidote, piedmontite ($a =$ yellow, $\gamma =$ deep rose, $\gamma \wedge 001$ cleavage $= 32°$). The mica is in flakes 3 or 4 millimeters in diameter and in amounts subordinate to those of the other dark constituents. The groundmass consists of microlites of oligoclase in slender and stout sections, and of microfelsitic intergrowths of a sodic plagioclase with quartz and probably orthoclase. Magnetite is scattered in the groundmass in small octahedral grains together with some small scales, probably of hematite. The apatite is in stout yellowish pleochroic prisms. Some sericite is developed along cracks in the plagioclase and some scattered piedmontite and calcite occurs in the groundmass.

Correlation and Age of the Porphyry.

The porphyry is in some features unlike the other igneous rocks in the Republic and can not be correlated definitely on its petrographic character. As it appears to have intrusive relations both to the Cretaceous rocks and to the hornblende andesites, and as it is older than the upper Eocene limestone, it is probably of the same or nearly the same age as the quartz diorite in the Massif du Nord. It may be a chilled intrusive phase of the quartz diorite batholith that was intruded into the rocks of the northern part of the Republic in Cretaceous time. The nearest known outcrops of quartz diorite are those south of Limbé and near Bahon, although intrusive bodies of considerable magnitude unquestionably underlie the metamorphosed volcanic rocks in Section Las Lomas, about 12 kilometers northeast of Savane La Cidra.

The variation in the mineral composition of the dacite porphyry from the normal contact porphyries of the quartz diorite might be accounted for by the conditions of oxidation and of considerably reduced pressure and temperature in the Cretaceous (?) rocks near the surface. The concretionary masses of iron and manganese oxides found on its surface are exactly similar, both in texture and in the relative proportions of iron and manganese, to those formed by the weathering of quartz diorite débris near Acul Samedi.

LATER QUARTZ DIORITE GROUP OF THE MONTAGNES DE TERRE-NEUVE.

Distribution and Structural Relations.

Rocks of the later quartz diorite group, so far as known, are confined to a narrow zone, about 11 kilometers in length, in the Montagnes de Terre-Neuve. They consist of a series of small elongated stocks and a few accompanying dikes and pegmatitic veins. At some places irregular

or laccolith-like bodies appear to have spread out laterally from areas near the apex of the main intrusive masses. These rocks were intruded, probably during Miocene time, through the older volcanic rocks and into the upper Eocene limestone. The exposed rocks of this group are predominantly chilled contact porphyries, although there are a few small bodies and dikes of coarser grained quartz diorite and granodiorite. Their distribution and structural relations and the associated ore deposits are considered more fully in the description of the Terre-Neuve district. (See pp. 425-459 and Plate II.)

Petrography and Chemical Composition.

Quartz diorite.—The quartz diorite phase of the intrusive at Hilaire, in the Commune of Terre-Neuve, is a gray rock of medium-grained texture in which the dark minerals are usually subordinate in amount, although hornblende may be abundant locally. It is similar in appearance to the Cretaceous quartz diorite shown in Plate XIX, *A*, except that it is of somewhat finer grain. Prisms of plagioclase and hornblende, grains of quartz, and in some rocks flakes of biotite can be recognized megascopically.

In thin section the rock has a somewhat porphyritic texture, containing euhedral to subhedral prisms of plagioclase and subhedral prisms of hornblende in a matrix of smaller grains of quartz and some orthoclase of later crystallization. Much of the hornblende may also be interstitial with the quartz, depending on its relative abundance. The plagioclase is in zoned subhedral prisms, generally with albite and Carlsbad twinning, from 2 to 4 millimeters in length. Extinction angles on combined twins and on the 010 zone show a composition ranging from andesine (Ab_{57} An_{43}) to oligoclase (Ab_{70} An_{30}). Rims of even more sodic oligoclase may be present on the more zonal crystals, so that the average plagioclase is probably near Ab_{65} An_{35}. The plagioclase forms from 45 to 50 per cent of the rock volume. Quartz is in formless interstitial grains between the prisms of plagioclase and hornblende. It is somewhat fractured and has a slight wavy extinction. The amount of quartz is rather high, forming 20 to 30 per cent of the rock. Orthoclase, in general very subordinate, is found interstitial like the quartz but may form irregular plates plastered on the outside of prisms of plagioclase. Orthoclase generally appears to form less than 5 per cent of the rock in this facies of the intrusive but is sufficient in amount to differentiate the rock from the Cretaceous quartz diorites, most of which contain no orthoclase.

Hornblende, which at some places forms 15 to 20 per cent of the rock, is pleochroic from yellow-green to olive-green, and some has a shreddy or uralitic appearance. The largest prisms of hornblende indent only the borders of the plagioclase, as they began to crystallize somewhat later than the calcic plagioclase. The hornblende is quite idiomorphic toward quartz. Diopside or augite is found only in subordinate amounts in some parts of

the rock, chiefly in rather small prisms and granules interstitial to the plagioclase. A small amount of brown biotite was noted in one section, associated with somewhat larger amounts of orthoclase, so that the rock apparently approaches a granodiorite in composition. The biotite was altering to chlorite. Magnetite, titanite, and apatite are the principal accessory minerals. Titanite is especially abundant in some rocks, owing in part probably to decomposition of an earlier titanium-bearing hornblende. Chlorite, calcite, and quartz are secondary minerals. Fibrous or uralitic-appearing hornblende may have been formed by the recrystallization of a more basic hornblende and is usually accompanied by grains of titanite and magnetite.

Granodiorite.—Rocks of this type were found only in Memé Valley as dikes or small intrusive bodies cutting the fine-grained porphyries. They are gray or slightly greenish rocks of medium grain, speckled with flakes of dark-brown biotite and grains of pyroxene or hornblende. (See Plate XX, *B.*) Plagioclase feldspar and quartz can be recognized. Close inspection shows that in some specimens the biotite occurs in poikilitic flakes enclosing other minerals.

In a thin section of a dike rock from a locality just south of the Roche Glissé workings (Plate XXII, *A*) the plagioclase is in euhedral to subhedral prisms between which are irregular grains of quartz, orthoclase, and biotite. The prisms of plagioclase are from 0.2 to 2 millimeters in length but average about 1 millimeter. The plagioclase is zonal, ranging from andesine, and in some crystals from sodic labradorite (Ab_{45} An_{55}), to oligoclase, and probably has an average composition of sodic andesine or oligoclase (Ab_{75} An_{25} to Ab_{70} An_{30}). Orthoclase occurs in irregular interstitial grains, some of them as much as 1 or 2 millimeters in diameter, generally untwinned. Many of the larger grains are poikilitic and inclose a few small prisms of plagioclase. The quartz is in irregular grains, some showing undulatory extinction. The brown biotite is in entirely irregular flakes which are interstitial to or inclose minerals of earlier crystallization, such as plagioclase, pyroxene, and iron ores. The flakes range from small specks up to pieces 2 or 3 millimeters in larger diameter. The pyroxene, probably diopside or some nonaluminous variety, is colorless to pale greenish in section and forms rather stout prismatic grains with ragged outline that very commonly inclose numerous grains of iron ore and small prisms of plagioclase. The angle $Z \wedge c$ is about 42°. A light-green hornblende is intergrown with or has replaced some crystals of diopside, forming an imperfect network and giving the crystals a mottled appearance. Small grains of massive hornblende also occur which are not associated with the diopside. Magnetite, the commonest accessory, occurs in irregular or octahedral grains. Titanite, epidote, and apatite are other minor accessories.

A chemical analysis of this rock and averages of some analyses of granodiorite and quartz diorite are given in the following table:

Chemical analysis of granodiorite from Memé Valley, average analyses of granodiorite and quartz diorite, and limits of variation of granodiorite.

	1	2	3	4
SiO_2	59.37	65.10	59.47	59–68.5
Al_2O_3	13.23	15.82	16.52	14–17
Fe_2O_3	3.45	1.64	2.63	1.5–2.25
FeO	4.25	2.66	4.11	1.50–4.5
MgO	3.76	2.17	3.75	1.0–2.5
CaO	5.63	4.66	6.24	3–6.5
Na_2O	3.69	3.82	2.98	2.5–4.5
K_2O	2.62	2.29	1.93	1–3.5
H_2O+	1.08	} 1.09	1.39	
H_2O-	0.06	}		
TiO_2	2.14	0.54	0.64	
P_2O_5	0.22	0.16	0.26	
MnO	0.17	....	....	
	99.67	100.00	100.00	

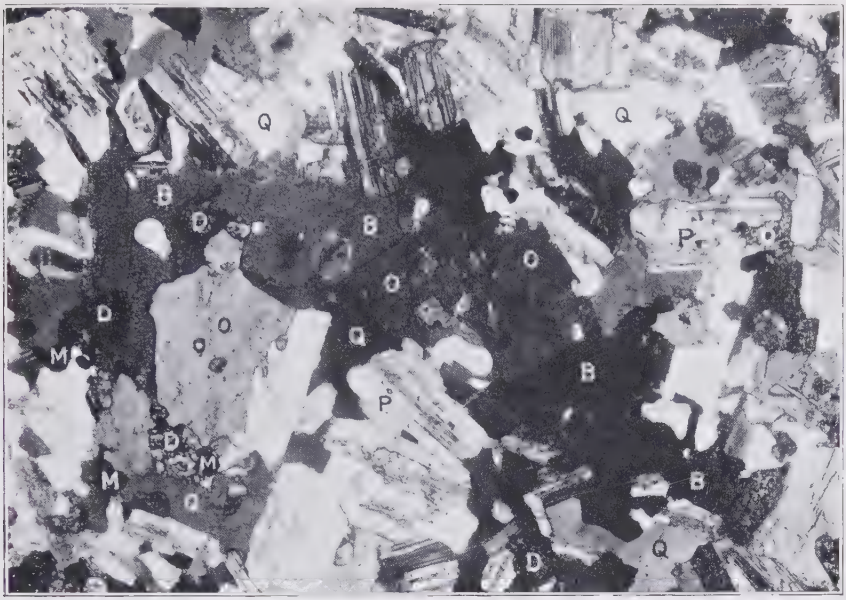
1. Granodiorite, Memé Valley, Republic of Haiti. H. S. Washington, analyst.
2. Average of 12 analyses of granodiorite. Daly, R. A., Igneous rocks and their origin, p. 25, 1914.
3. Average of 20 analyses of quartz diorite. Daly, R. A., op. cit., p. 26, 1914.
4. Limits of variation of granodiorite. Lindgren, Waldemar, Granodiorite and other intermediate rocks: Am. Jour. Sci., 4th ser., vol. 9, p. 272, 1900.

An approximate mode, determined by a combination of measurement by the Rosiwal method and by chemical calculation, and the norm are shown in the following table:

Approximate mineral composition and norm of Memé granodiorite.

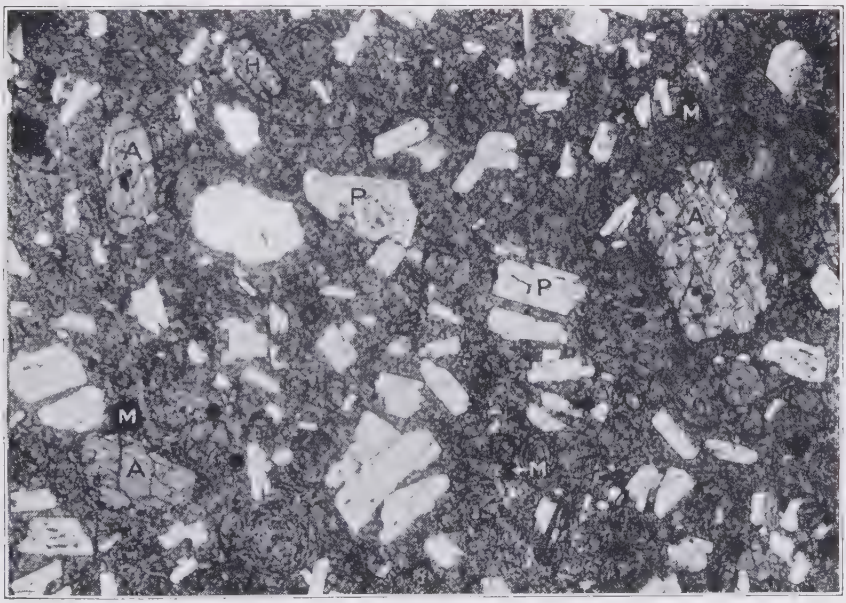
Approximate mineral composition.		Norm.	
Quartz	17.9	Quartz	13.18
Orthoclase	8.9	Orthoclase	15.68
Andesine (Ab_{70} An_{30} ±)	40.7	Albite	31.34
Biotite	12.7	Anorthite	11.48
Diopside	7	Diopside	12.18
Hornblende	4	Hypersthene	5.37
Magnetite	3.7	Ilmenite	4.07
Ilmenite	2.1	Magnetite	4.99
Apatite	0.4	Apatite	0.51
Titanite	1	The rock is dacose (II.4″.2″.″4).	

The rock is lower in silica and higher in iron and magnesium oxides than the average analysis of the granodiorites, the amounts of these oxides clearly corresponding more closely to those in the average quartz diorite. The alumina is low for rocks in the diorite or granodiorite families, but in this respect the rock is similar to the Cretaceous quartz diorite from Morne Madeleine. (See p. 292.) The titanium is rather high. The chemical calculations indicate that ferric iron probably replaces the alumina to some extent in the biotite and hornblende, and the pyroxene



A. PHOTOMICROGRAPH OF GRANODIORITE FROM MEMÉ VALLEY, COMMUNE OF TERRE-NEUVE.

O, orthoclase; P, plagioclase; Q, quartz; B, biotite; D, diopside; M, magnetite. Crossed nicols, ×30.



B. PHOTOMICROGRAPH OF GLASSY PYROXENE ANDESITE WITH PERLITIC TEXTURE FROM SOUTH SLOPE OF MORNE DUMURAILLE, COMMUNE OF TERRE-NEUVE.

P, plagioclase; A, augite; H, hypersthene; M, magnetite. Ordinary light, ×90.

presumably is a variety of diopside. The relative amounts of the calcium, sodium, and potassium oxides correspond to those of Daly's average granodiorite, and the ratio of the orthoclase to the plagioclase in the mode brings the rock well within the limits of the ratio that is common in rocks of the granodiorite family. The low percentage of orthoclase and the high percentage of ferromagnesian minerals indicate, however, that the rock approaches a diorite in composition.

Dacite porphyries.—Contact porphyries are the most widespread type of this group. Although they differ in appearance, owing to alteration and variations in texture, they have the same general character under the microscope. The porphyries are light gray to dark gray or greenish gray, in places stained yellowish or brownish by weathering, and commonly much jointed. The plagioclase phenocrysts, prisms of hornblende, and grains of quartz can easily be recognized with the unaided eye or with a hand lens, unless alteration has been so intense as to have recrystallized the hornblende or altered the plagioclase.

In thin section the plagioclase phenocrysts are in more or less euhedral zonal prisms, some of them fragmental, and from 1 to 3 millimeters in length. They are generally andesine, ranging in composition from Ab_{60} An_{40} to Ab_{65} An_{35}, although phenocrysts as calcic as labradorite (Ab_{40} An_{60} to Ab_{50} An_{50}) are found in some specimens. These phenocrysts constitute from 30 to 50 per cent of the rock volume. The quartz is in rounded bipyramidal crystals, some of them fractured, the largest 1 millimeter in diameter. Quartz phenocrysts are generally rather sparingly present, forming from a small percentage to about 10 per cent of the rock, most of the quartz being in the groundmass. The hornblende is olive-green or blue-green and may be partly resorbed to magnetite or recrystallized to a shreddy uralitic variety. The hornblende alters to chlorite, iron oxides, and calcite. A colorless augite is sparingly present in some sections, generally surrounded by a granular aggregate of albite, chlorite, titanite, and other secondary minerals. The groundmass in most specimens is a fine-grained intergrowth of sodic andesine or oligoclase with quartz and probably some potash feldspar. Magnetite and apatite are accessory minerals. The groundmass of some of the specimens contains abundant microlites of a uralitic hornblende, apparently of secondary origin. Sericite, chlorite, calcite, and quartz are secondary minerals. Titanite is generally present in traces and may be abundant where alteration has decomposed some of the ferromagnesian minerals. A more complete description of the alteration of these rocks is given in the description of the ore deposits of the Terre-Neuve district (pp. 439-440).

Dike rocks.—A small number of dikes cut the older andesitic lavas outside of the main intrusive zone in the Terre-Neuve region. A large prominent dike of this type at Rocher, southeast of Terre-Neuve village, is the country rock of some of the copper veins. The rock is a gray porphyry

containing white plagioclase phenocrysts 2 to 3 millimeters in length, some hornblende prisms, and a few grains of quartz in a dark-gray aphanitic groundmass. Except for a few flakes of biotite partly altered to chlorite the rock is much like the contact porphyries. The plagioclase phenocrysts are sodic andesine with borders of oligoclase. The groundmass consists of oligoclase, some quartz, and potash feldspar.

Aplites and pegmatites.—Aplitic and pegmatitic facies of the intrusive are not abundant. Pegmatite veins consisting of untwinned orthoclase plagioclase, quartz, and biotite and some pyrite and chalcopyrite were seen in Memé Valley. An aplitic rock of rather unusual type, consisting largely of albite, a little quartz, and spherulitic or radial growths of muscovite, was found near Jeanty Ravine. Some chlorite, titanite, and magnetite are present in the rock.

RELATIONS OF THE VARIOUS TYPES.

The dacite porphyries make up the larger part of the intrusive masses and generally were the first rocks intruded. They represent quickly chilled magma that first came into contact with the relatively cold volcanic rocks and limestones. The porphyries in Memé Valley have been cut by dikes and irregular masses of the granodiorite. The relation of the quartz diorite at Hilaire to the porphyries is not known. The intense alteration of the porphyries at some places and the general absence of this alteration in the coarser-grained rocks indicate that the coarser-grained rocks are intrusive into the chilled porphyries. Veins of pegmatite and aplite cut both the dacite porphyries and the granodiorite. The relative age of the surrounding dikes, such as the one at Rocher, is not known. This dike does not have chilled borders and may be one of the later intrusives. Although no analyses of the altered porphyries are available they probably are more similar in composition to the quartz diorite at Hilaire than to the fresh granodiorite at Memé, which is a later differentiate, probably richer in potash and soda.

Metamorphic Rocks Entirely or in Part of Igneous Origin.

DISTRIBUTION AND GENERAL FEATURES.

Metamorphic rocks largely of igneous origin are found at a number of places in the northern region. The most notable localities where these rocks were found during the reconnaissance are on the North Plain at Morne Beckly and west of Le Trou, near Grande-Rivière du Nord, west of Limbé, on Limbé Mountain, and in Section Las Lomas, northeast of St.-Michel. All the metamorphic igneous rocks at these localities appear to have been derived by intense dynamic and hydrothermal contact metamorphism from the earlier basalts and associated pyroxenites and peridotites, probably during the folding and batholithic intrusions of Cretaceous

time. The more intense phases of this metamorphism have resulted in the formation of chloritic, amphibolitic, talcose, and serpentinous rocks and in the production of local zones of schists.

The following table gives a brief classification of the more notable types of metamorphic and igneous rocks in the northern region. The more notable types of metamorphic rocks are described in the following text.

Classification of igneous and metamorphic rocks in the northern part of the Republic of Haiti.

Original state of rocks.	Present state of rocks.	Age or relations.
1. Sediments.		
Impure quartz sandstone (?).	Garnetiferous quartz-mica schist.	
Limestones	Metamorphic limestone schists and marble.	Probably Paleozoic.
2. Basaltic lavas and tuffs.....	Fine-grained or porphyritic "greenstones"; and amygdaloidal basalts.	
	Uralitized and albitized basalts; chloritized basalts; chlorite schists; some amphibolites (?).	Early or middle Mesozoic (Triassic (?) and Jurassic).
Tuffs and calcareous tuffs (?)...	Chlorite schists; chloritic calc schists.	
3. Basic and ultrabasic intrusives.		
Diabases and gabbros.....	Uralitized and albitized diabases; metadiabases; epidosites; hornblende schists.	Associated with and probably intrusive into the basaltic lavas and tuffs.
Pyroxenites (?)	Amphibolites and hornblende schists.	Early or middle Mesozoic.
Peridotites	Partially serpentinized peridotites; talc schists; serpentines.[a]	
4. Andesites and dacites.....	Andesites and dacites. Locally albitized and sericitized and otherwise slightly altered.	Jurassic (?), possibly in part early Cretaceous.
5. Sediments. Claystones, siltstones, sandstones, limestones. Largely nonmarine but partly marine.	Chloritic or sericitic argillites; slaty shales and sandstones; calcareous sandstones; crystalline limestones and marble. Locally schistose.	Early or middle Mesozoic.
6. Quartz diorite and associated rocks.	Quartz diorite, etc., locally sheared and fractured.	Late Cretaceous.
7. Basaltic and andesitic lavas, diabase, essexite. Zeolitized.	Practically same, except for local alteration.	Late Cretaceous or early Eocene. Exact age unknown.

[a] Large areas of serpentine were not found in the Republic of Haiti but are found in the Dominican Republic. (See p. 287.)

AMPHIBOLITES AND HORNBLENDE SCHISTS.

Rocks generally without schistose structure but in some places showing it and consisting predominantly of hornblende are found southwest of Limbé and on the North Plain at Morne Beckly and east of Le Trou. Practically all gradations from incipient amphibolitization of basaltic rocks to rocks that have been fully recrystallized to amphiboles are found. Generally some chlorite, talc, or serpentine is found in the amphibolites, and iron ores are invariably present.

Dark-gray amphibolites, which on weathered surfaces are conspicuously porphyritic, are found east of Le Trou along the road between Cap Haïtien and Ouanaminthe. These rocks were originally coarsely porphyritic, containing many large crystals of diopside or augite from 1 to 5 millimeters in diameter. On freshly broken surfaces the rocks are dark green and the porphyritic texture is not so apparent. In thin section some of the rocks show remnants of unaltered pyroxene or less commonly of unaltered olivine. One rock was completely converted to pale amphibole with some chlorite and iron oxides, though the original porphyritic texture could be easily recognized. In another rock from the same locality and of similar appearance the phenocrysts, which were largely diopside, were altered to a pale scarcely pleochroic amphibole with some flaky serpentine. Along fractures in some of the phenocrysts green isotropic grains, probably of pleonaste, have been deposited.

A grayish-green hornblende schist from Morne Beckly is greasy to the touch and is spotted with dark-green patches of chlorite. Microscopic examination shows that it was derived by metamorphism from a coarse porphyritic basalt or pyroxenite probably similar to rocks east of Le Trou. The groundmass of the rock now consists largely of a very pale amphibole with considerable serpentine or chlorite and iron ores. Along seams in the rock the opaque iron ores and in some places reddish-brown transparent grains, probably of pictotite or chromite, have been deposited. The phenocrysts, which resemble in outline large crystals of pyroxene and olivine (?), are completely altered to serpentine and interlacing needles of actinolitic hornblende, with some chlorite.

The ultrabasic rocks from which these serpentinous amphibolites were derived probably are of the same age as the basic rocks from which the nickel-bearing serpentines of the Dominican Republic and of Cuba were derived. It is noteworthy that no areas of serpentine rocks were found in the Republic of Haiti. Amphibole is a major constituent and serpentine is a minor constituent of most of the altered rocks. An augite peridotite found in Section Las Lomas showed only incipient serpentinization (see p. 288).

Some amphibolites and hornblende schists at Morne Beckly are composed of greenish-black to gray hornblende in thin fragments that are pleochroic from colorless or yellowish to blue-green ($\alpha = 1.62 \pm .003$, $\beta = 1.635 \pm .003$, $\gamma = 1.645 \pm .003$). The hornblende is arranged in parallel,

radial, or confused aggregates and in some rocks in bundles of acicular crystals 5 to 6 centimeters in length. Between the dark crystals of hornblende or along shear planes some yellowish or brownish asbestiform actinolite is found in places. The complete recrystallization of these rocks obscures their texture and origin. Probably, however, they represent only the final stage in the amphibolitization of rocks such as those just described.

TALC SCHIST.

A relatively pure talc schist derived through metamorphism from an enstatite-bearing rock was found on Morne Beckly. About 15 per cent of the rock consists of remnants of a colorless orthorhombic pyroxene, and the rest is made up of talc and iron oxides. The rock appears to have been brecciated or sheared. Talc and some stringers of iron ores replace the primary constituents, starting from the fracture lines. Enstatite is the only primary mineral preserved in the rock.

CHLORITIC SCHISTS.

Chlorite schists occur as country rock associated with the metalliferous veins in Section Cormiers, west of Grande-Rivière du Nord, and in Section Las Lomas, northeast of St. Michel. These light-greenish schists are spotted with dark flakes of chlorite and consist predominantly of calcite and chlinochore, with some iron ores and pyrite. Quartz, chalcopyrite, or titanite may be present. The schists may have once been predominantly chlorite and clearly show replacement of the chlinochore by later calcite. Although the exact origin of these calcitic chlorite schists is unknown, they may have been formed by chloritization of basaltic rocks along zones of hydrothermal activity, and the resulting chlorite rocks, during subsequent periods of mineralization, were recrystallized and partly replaced by calcite and quartz carrying sulphides. Almost complete chloritization of amygdaloidal basalts was observed in lavas collected at habitation La Selle, in Section Cormiers north of the locality where the chlorite schists were found. This type of schist, so far as known at present, is confined to mineralized shear zones.

A different type of chloritic schist is found on Morne Beckly. This is a reddish-brown distinctly schistose rock spotted with deep-green flakes of chlorite. In thin section the rock is seen to be of fragmental origin and is probably a metamorphosed tuff. The fragments are angular and of varying size and are contained in a clouded base, consisting largely of calcite with scattered flakes of chlorite and some recrystallized iron oxides. The fragments appear to be largely of igneous origin and are altered to pale amphibole, talc, or chlorite. Some fragments consist of calcite and may possibly be fragments of limestones.

Summary of the Relations of the Extrusive and Intrusive Series.

Briefly summarized, the igneous rocks of the northern region comprise an older complex series of volcanic rocks and a younger group of batholithic rocks that have intruded the volcanic rocks. The old basement on which the volcanic series rests has largely been engulfed in the quartz diorite batholith in the central part of the Massif du Nord, although patches of it are probably preserved on the North Plain and on Tortue Island north of the main axis of intrusion. The structural relations within the volcanic series are only imperfectly known. In general, there appears to be an older basaltic series and a younger andesitic series, but it is doubtful if a complete section including both series is to be found at all places. The volcanic rocks contain some old intrusive igneous bodies of basic or ultrabasic composition that are associated with and presumably intrude the oldest basaltic rocks.

A blanket of Cretaceous sedimentary rocks overlaps the surface of the younger volcanic rocks. In middle or late Cretaceous time, when these sediments had attained considerable thickness, all the rocks were intensely folded and were intruded by the batholith of quartz diorite.

Among the latest lavas of late Cretaceous or early Eocene age are some basaltic and andesitic rocks, in part of alkaline composition. Their relations to the quartz diorite are unknown.

Later folding, possibly in Miocene time, was accompanied by minor stocks of quartz diorite and granodiorite that intruded the older volcanic rocks and the Tertiary limestones in the Montagnes de Terre-Neuve.

The sections given in Figure 18 are somewhat generalized, but they show diagrammatically the relations of some of the igneous and sedimentary rocks. The minor intrusions south of Limbé (in section *C*) lie along the crest of an anticlinal arch, the core of which consists of the older basaltic rocks, and the south flank and probably also the north flank are composed of the younger andesitic lavas.

Figures 27 and 28, on pages 442-444, show in sections the structural relations of the post-Eocene intrusives in the Montagnes de Terre-Neuve.

Presumably the series of rocks ranging from the early basaltic lavas in Jurassic (?) or earlier Mesozoic time through the andesitic and dacitic lavas to the batholithic intrusions of quartz diorite of late Cretaceous age comprise a single cycle of igneous activity.

The relation of the later Miocene (?) quartz diorite group to the earlier cycle of activity is not apparent. The similarity of the chemical analyses of the Cretaceous quartz diorite and the post-upper Eocene granodiorite is very marked and surely indicates that these rocks were derived from a similar parent magma, though probably during separate cycles of igneous activity. (See pp. 292 and 304.)

The later basaltic and alkaline andesitic rocks of the vicinity of Ennery and of the Montagnes de Terre-Neuve appear to have been erupted along

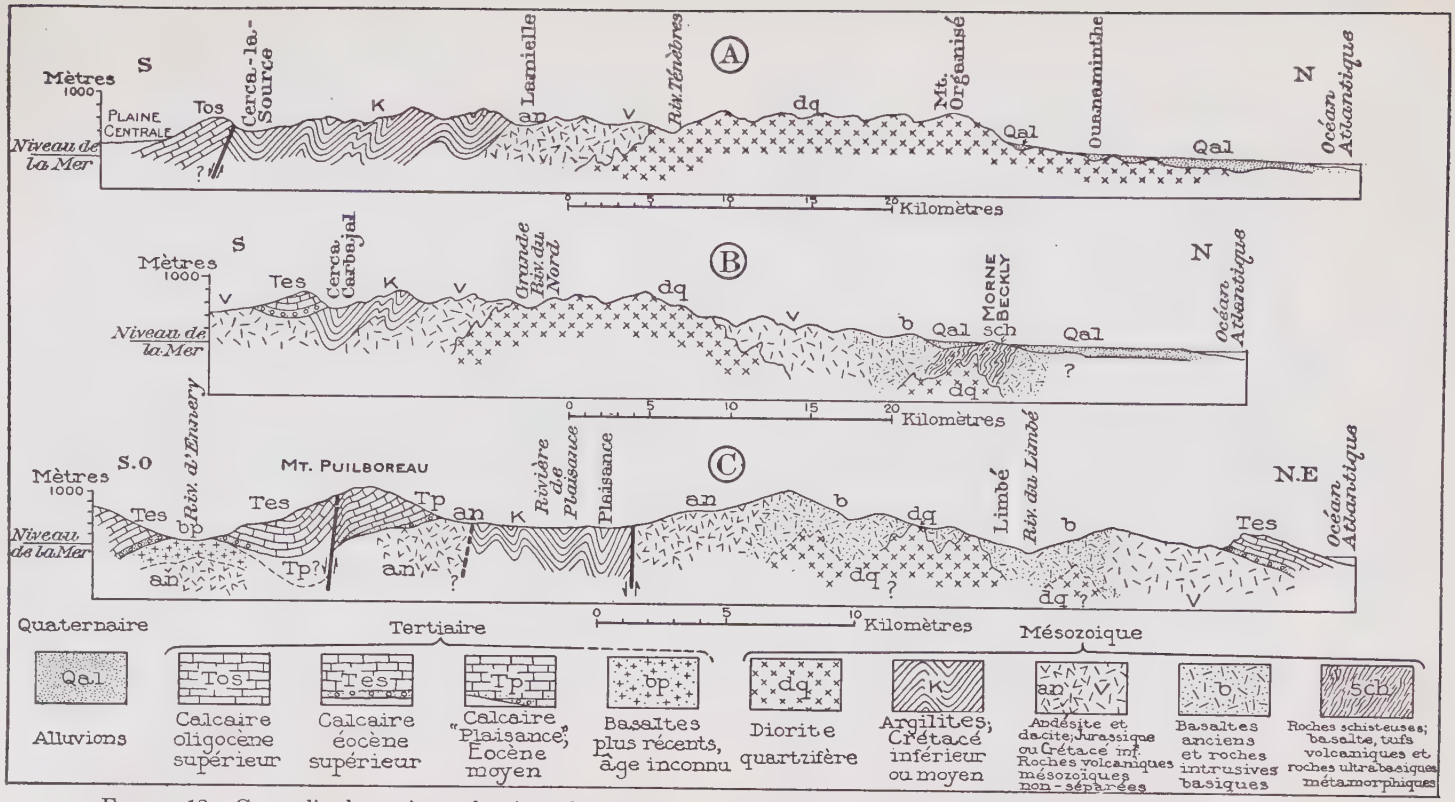


FIGURE 18.—Generalized sections showing the relations of the igneous and sedimentary rocks in the Massif du Nord.

A, Section from Cerca-la-Source to Ouanaminthe. *B*, Section from Cerca-Cabajal to the vicinity of Morne Beckly near Limonade. *C*, Section from the Rivière d'Ennery between Ennery and Poteau through Plaisance Valley and Limbé to the north coast.

a late Cretaceous (?) structural trough south of the main axis of the Cretaceous batholith. They probably are relatively minor eruptions belonging to the later stages of the Mesozoic cycle of activity.

CENTRAL REGION.

General Features and Distribution of Igneous Rocks.

In the central part of the Republic there were at least three periods of igneous eruptions—Cretaceous or Eocene, middle or upper Oligocene, and Miocene. Basaltic lavas and tuffs representing the earliest of these periods of eruption were definitely recognized at only two localities, one southwest of Las Cahobas and the other in the central part of the Chaîne des Mateux. Nephelite basalts of Oligocene age were found northeast of Thomazeau, and basalts of the same composition near Saut d'Eau may be of the same age or possibly younger. Miocene basaltic rocks were found in the Miocene sedimentary rocks just north of the Cul-de-Sac Plain and north of l'Arcahaie.

So far as known, all the igneous rocks are extrusive—lavas or tuffs—and no indications of intrusive activity were recognized in any part of the central region. Fragments of quartz and of yellowish iron-rich epidote in some of the Miocene sedimentary beds just south of St.-Marc probably were derived from the central parts of the Montagnes Noires, where these minerals are found in and associated with the intrusive rocks.

Pre-Tertiary or Lower Eocene Basaltic Rocks.

Basaltic lavas of pre-Tertiary or lower Eocene age are exposed about 4 kilometers southwest of Las Cahobas, where the road to Mirebalais crosses the gap in the Montagnes Noires. The mountains are anticlinal, and the basalts underlie the upper Eocene limestone near the center of the gap. (See Fig. 19.)

Basaltic volcanic rocks crop out in small areas south and east of Couyau, near the crest of the anticlinal arch of the Chaîne des Mateux. They probably lie at the base of the upper Eocene limestone or underlie it. Most of the outcrops are deeply weathered and have a reddish or yellowish iron-stained soil. At one exposure a basaltic tuff composed largely of altered basaltic glass and containing small Foraminifera is interbedded in the upper Eocene limestone. This material may represent reworked tuff in the basal parts of the upper Eocene limestones.

Exposures of the basal parts of the Eocene limestone and any underlying or interbedded volcanic rocks may be found in the unexplored deep valley north of Couyau that drains westward to Mont Rouis.

PETROGRAPHY.

Hypersthene basalts.—Two specimens collected southwest of Las Cahobas are hypersthene basalts.

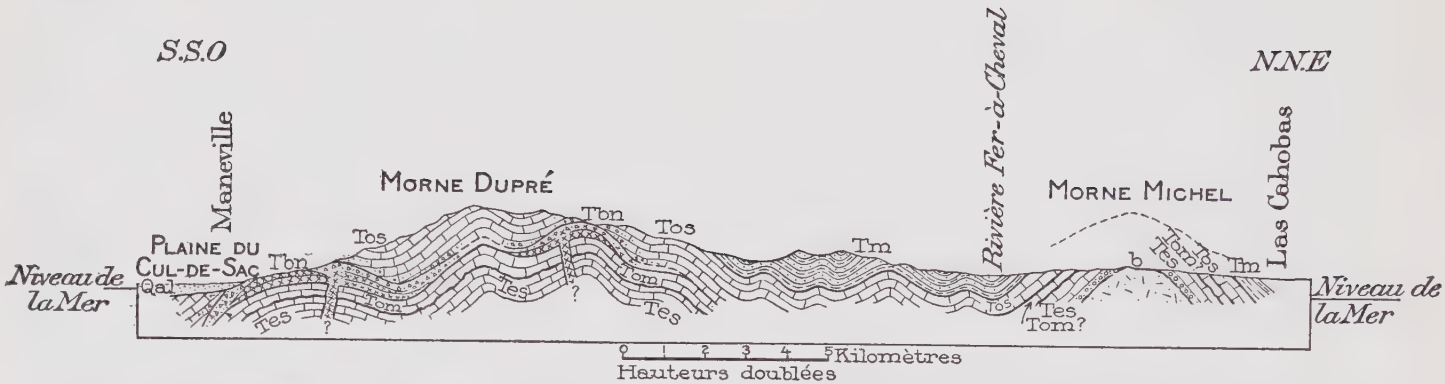


FIGURE 19.—Section across the Montagnes du Trou d'Eau and the Montagnes Noires from Maneville to Las Cahobas, showing the relations of the middle Eocene basalts in the Montagnes Noires and the supposed relations of the nephelite basalts to the middle and upper Oligocene limestones in the Montagnes du Trou d'Eau.

Qal, Quaternary alluvium; Tm, Miocene; Tos, upper Oligocene limestone; Tbn, bedded lavas, agglomerates and tuffs, principally nephelite basalts; Tom, middle Oligocene limestone; Tes, upper Eocene limestone; b, early Tertiary or Mesozoic basaltic lavas.

The rock has a sheet-like jointing. One of the specimens is a dark-gray to black highly vesicular lava, with vesicles 3 to 4 millimeters in diameter. Some of the vesicles are lined with altered glass or chloritic substances and opal. In thin section the lava is seen to contain prisms about 1 millimeter in length of a nearly colorless orthorhombic pyroxene. The fine groundmass shows a flow structure and consists of thin prisms of labradorite in a base of brown partly altered glass. The hypersthene phenocrysts may be in clusters of as many as six or seven crystals. Small hypersthene microlites are present in the glassy base. There are a few scattered prisms of plagioclase about 0.2 millimeter in length, and a few greenish to brownish grains of augite of about the same size. Fine specks of magnetite are scattered in the groundmass.

The second specimen is a greenish-gray rock of aphanitic texture. The hypersthene phenocrysts are altered to greenish serpentine and a mineral of low refraction ($n=1.47$), possibly some form of silica. There are a few grains of unaltered augite. The groundmass of this rock is similar in texture to the other lava except for a smaller proportion of glassy base.

Tuff.—No lavas suitable for petrographic study were collected in the Chaîne des Mateux. The tuffaceous rock east of Couyau interbedded in the upper Eocene limestone is a light-brownish rock resembling a much-weathered porphyry. It consists of fragments of a brown fine-vesicular altered glass or palagonite in a matrix of calcareous material. The original shapes of the glass fragments have been destroyed, either by alteration or transportation.

Nephelite Basalts.

Distribution and structural relations.

Near Saut d'Eau.—Southwest of Saut d'Eau (Ville Bonheur) the nephelite basalts rest on an eroded surface of limestone of middle Oligocene age. Along the trail from Mirebalais to Saut d'Eau, 3 kilometers southeast of Saut d'Eau, the basalts rest on soft, white marly beds that are considered a marly facies of Oligocene or Eocene limestone, which is also found on the hill west of Saut d'Eau. The relations of the basalts to the Miocene beds of the Artibonite Valley are not known. The basalt floors the open grass-covered savanna southwest of Saut d'Eau called Savane Madame Michel. Between this savanna and the Savane Madame Michaud, to the southwest, the trail to Fond-des-Orangers crosses low hills, where the underlying middle Oligocene limestone crops out. Northwest of the trail, just beyond the divide on Savane Madame Michaud, a more or less conical dissected hill rises about 200 meters above the savanna. The southeast slopes consist of bedded volcanic material and some vesicular flows. The bedded material is in thin, even beds, which in some places dip 20° to 30° southwestward. It consists of small fragments, some of which are partly rounded, and a few fragments of vesicular lava larger than a man's head. The general character of the material and

bedding indicate that it is partly reworked volcanic tuff and agglomerates, although their source was not discovered. (See Pl. XVIII, *B*, p. 280.) They probably overlie the flows to the east and south. The basaltic lavas extend southward into the valley called Fond-des-Orangers, where the underlying limestone is of upper Eocene age.

Near Thomazeau.—Nephelite basalts of the same character as those found at Saut d'Eau are exposed at the foot of the mountains northeast of Thomazeau and north of Maneville. On the trail from Thomazeau to Cormillon, at the foot of the mountains, conglomeratic beds near the base of the overlying upper Oligocene limestone contain pebbles of basalt and of a limestone, presumably of upper Eocene age. All the igneous pebbles in this conglomerate consist of altered nephelite basalt containing abundant crystals of olivine and generally are well rounded, as are the few pebbles of limestone. The igneous pebbles may be reworked tuffaceous and agglomeratic material. About 4 kilometers northeast of Thomazeau there are exposures of material that appears to consist of reworked agglomerates and tuffs, loosely cemented and dipping as much as 15° to 18°.

Along the trail from Cornillon to Marché Canard, on the north slope of the mountains, about 1 or 2 kilometers beyond their crest, weathered basalt underlies the upper Oligocene limestone. This basalt presumably is the same as that exposed farther southwest, near Thomazeau, although no specimens were examined petrographically. (See Fig. 19, p. 313.)

PETROGRAPHY AND CHEMICAL COMPOSITION.

The massive basalts of this series are dark-gray rocks when unaltered, although some are brownish. Extremely vesicular or scoriaceous lavas may be brown, coated with yellowish alteration products. The weathered surfaces of the gray rocks are bleached to a rusty brown, and vesicular lavas may be deeply pitted. The lavas from Saut d'Eau and Maneville are of exactly the same appearance and mineral composition, and in thin sections they are practically indistinguishable.

Nephelite basalt.—A typical unaltered rock from a locality about 2 kilometers northeast of Maneville is dark gray and not noticeably porphyritic but contains small phenocrysts, the largest about 1 millimeter in length, of glassy olivine and of augite in a dark-gray dense groundmass.

In thin section the texture is porphyritic with phenocrysts of olivine and augite in a fine-grained holocrystalline groundmass of augite, nephelite, and zeolites. (See Pl. XXIII, *B*.) The unaltered olivine phenocrysts are rounded to subhedral crystals of characteristic outline or are straight cross-fractured prisms, partly in clusters. A yellowish to brownish-yellow augite is less common as phenocrysts. It usually occurs in long, thin, cross-fractured prisms, which make up about 5 to 10 per cent of the rock. The augite is zonal, with extinction on 010 ($\perp \beta$), ranging from 42° to 52° on the outside, pleochroic ($\alpha = 1.70, \gamma = 1.72+$). The augite

in the groundmass is in small prisms and microlites. Titaniferous magnetite and probably ilmenite are the principal accessory minerals and form irregular grains and clustered aggregates. Both apatite in small prisms and some melilite are scattered in the groundmass in minor quantities. The nephelite forms irregular grains except near borders of the miarolitic cavities, where it forms stout hexagonal prisms that are sharply idiomorphic against the surrounding later crystallized zeolites. (See Pl. XXIII, *B*.) The nephelite is perfectly clear and unaltered. The zeolites scattered in the groundmass and filling the cavities in the rock could not be definitely identified.

As the nephelite is clear and unaltered in contact with the zeolites, some of the zeolites may be of primary origin. Small amounts of calcite and analcite, both probably of secondary origin, are present in the rock, generally in cavities with the zeolites.

The mineral composition of the rock could be only roughly estimated because of the texture of the groundmass and is about as follows: Olivine, 15 per cent; augite, 50 per cent; nephelite, 15 per cent; iron ores, melilite, and apatite, 10 to 12 per cent; zeolites, 8 to 10 per cent.

A chemical analysis of this rock, an analysis of a similar rock from Grenada, British West Indies, and average analyses of nephelite and melilite-nephelite basalts for comparison are given in the following table:

Analysis of nephelite basalt from Maneville, an analysis of a similar rock from Grenada, and average analyses of nephelite basalts.

	1	2	3	4
SiO_2	38.64	42.83	39.87	37.56
Al_2O_3	11.14	10.92	13.58	10.08
Fe_2O_3	5.35	4.33	6.71	6.82
FeO	5.31	8.82	6.43	5.94
MgO	13.04	14.02	10.46	15.32
CaO	14.40	13.20	12.36	13.82
Na_2O	3.43	3.24	3.85	3.11
K_2O	1.90	.64	1.87	1.53
H_2O+	3.01	1.80	2.22	2.52
H_2O-	.29	....		
TiO_2	2.85	.05	1.50	2.66
P_2O_5	.71	.39	.94	....
MnO	.14	.12	.21	.06
	100.21	100.36		

1. Nephelite basalt, near Maneville, Republic of Haiti. H. S. Washington, analyst.

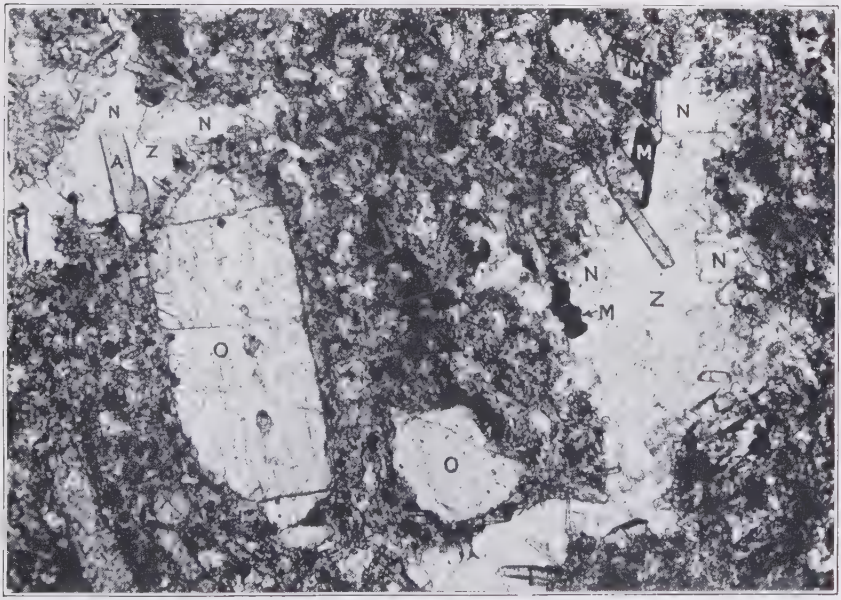
2. "Olivine basalt," Grenada, British West Indies. J. B. Harrison, analyst. Rocks of Grenada, p. 10, 1896. Given by H. S. Washington in Chemical analyses of igneous rocks, U. S. Geol. Survey Prof. Paper 99, p. 709, 1917.

3. Average of 26 analyses of nephelite basalt. Daly, R. A., Igneous rocks and their origin, p. 33, 1914.

4. Average of 5 analyses of melilite-nephelite basalt. Daly, R. A., op. cit., p. 33.

A. PHOTOMICROGRAPH OF BASALT FROM THE MASSIF DE LA SELLE, NORTH OF RIVIÈRE GOSSELINE.

P, plagioclase; D, diopside; O, olivine; S, serpentine; I, ilmenite. Ordinary light, ×90.



B. PHOTOMICROGRAPH OF NEPHELITE BASALT FROM THE VICINITY OF MANEVILLE.

O, olivine; A, titaniferous augite; N, nephelite; M, titaniferous magnetite; Z, zeolites. Ordinary light, ×90.

The norm of the Maneville nephelite basalt, calculated according to the quantitative classification, is as follows:

Norm of Maneville nephelite basalt.

Anorthite	9.48	Calcium orthosilicate	7.75
Leucite	8.72	Magnetite	7.78
Nephelite	15.70	Ilmenite	5.40
Diopside	25.10	Apatite	1.71
Olivine	15.80		

The rock is uvaldose ((III) IV. 2.3.2".2.)

In chemical composition the rock falls between Daly's nephelite and melilite-nephelite basalts, except that it is higher in calcium and slightly higher in titanium. The iron oxides are somewhat lower. The gradation toward melilite-nephelite basalt is also indicated by the presence of some calcium orthosilicate in the norm.

Some of the basalts at this locality are notably higher in augite and iron ores than the rock analyzed. In a specimen collected about half a kilometer northeast of Maneville the groundmass is composed largely of augite prisms and microlites together with a smaller percentage of interstitial nephelite and zeolites. Besides the accessory minerals it contains small brownish cloudy grains of an isotropic feldspathoid, probably haüynite or some member of the sodalite group, and flakes of reddish-brown biotite. The olivine in this rock is partly altered to serpentine and iron ores. Calcite accompanies the zeolites, both in the groundmass and in the cavities, and these minerals are probably to some extent secondary, although probably of late magmatic or deuteric origin. The augite probably comprises about 60–65 per cent.

Haüynite-nephelite basalt.—A specimen collected about 2 kilometers northeast of Thomazeau contains 3 to 5 per cent of haüynite as an accessory mineral. In thin section it shows hexagonal cross sections about 0.2 millimeter in diameter, generally clouded with brown or gray dusty inclusions, some of them in sectors or symmetrically arranged. Some sections are elongated, forming hexagonal prisms, which are probably due to dodecahedral twinning. Reddish-brown biotite is also present in small flakes.

Zeolitized nephelite basalt.—A brownish-gray rock, collected about 4 kilometers southeast of Saut d'Eau, is a nephelite basalt containing zeolites. It contains scattered vesicles and amygdules and is speckled with brownish-yellow grains of olivine altering to serpentine and iron oxides. In thin section the olivine is seen to occur in euhedral to subhedral crystals, some of which are marked by embayments of the groundmass. The augite phenocrysts are brownish green and have the characteristic zonal and "hourglass" structure. The augite is partly in very long prisms whose ratio of length to width is more than 10 to 1. This rock differs from some of the basalts in the development of the nephelite, which may be in relatively large crystals that poikilitically inclose the augite and accessories of the groundmass, and in the presence of considerable analcite,

which forms part of the base and replaces the nephelite. The mineral composition of the rock is approximately as follows: Olivine, 10 per cent; augite, 60 per cent; nephelite, 7 (?) per cent; iron ores, 5 per cent; analcite, 10 (?) per cent; zeolites, 8 (?) per cent. Apatite is an accessory mineral.

Melilite-nephelite basalt.—A large vesicular bomb or fragment from the bedded volcanic débris northwest of Savane Madame Michaud is a melilite-nephelite basalt. It differs from the other nephelite basalts only in the presence of a few small yellowish crystals of melilite, some of which have characteristic biconcave sections.

RELATIONS AND ORIGIN OF THE LAVAS.

In six sections studied from both localities and in specimens of conglomeratic volcanic débris that included fragments of lava, none of the basalts contained feldspar. The lavas from Thomazeau, from near Maneville, and from Saut d'Eau are remarkably similar in petrographic character. Accordingly, the lavas at these different localities must either have been derived from the same parent source of magma or the magmas must have had a similar genetic history.

As the lavas overlie the middle Oligocene and Eocene limestones the magmas in reaching the surface must have passed through at least a thousand meters of limestone. The uniformity of the lavas and the failure to find more siliceous types of igneous rocks associated with them indicates that the magmas were fully formed before they reached the chambers or conduits of the volcanoes from which they were erupted. A more extended study might, however, reveal the presence of other types of lavas.

AGE OF THE ERUPTIONS.

As the basaltic rocks at Saut d' Eau and northeast of Thomazeau are of exactly the same petrographic character and contain similar associated beds of reworked volcanic débris the eruptions in the two localities probably occurred at the same time, although this has not been proved by studies of the structure. The basalts at Saut d'Eau are of post-middle Oligocene age, and those near Thomazeau are overlain by upper Oligocene limestone. If the rocks at the two localities are of the same age the eruptions occurred in late middle or early upper Oligocene time. No evidence was found during the field work to indicate that the eruptive rocks were ever continuous between the two regions.

In the San Juan Valley and the valley of Rio Yaque del Sur, in the Dominican Republic, nearly flat-lying beds of limburgite capping mesas and upland areas of gravel are considered Pleistocene.[1] The fact that these limburgites are probably of similar composition to the nephelite basalts of the Republic of Haiti indicates that eruptions of lava of

[1] A geological reconnaissance of the Dominican Republic: Dominican Rep. Geol. Survey Mem., vol. 1, p. 203, 1921.

ultrabasic composition may have occurred intermittently over a considerable part of later Tertiary time. The lavas at Saut d'Eau may therefore be younger than those near Maneville, but their relation to the Miocene beds of the Artibonite Valley is not known.

Miocene (?) Basaltic Rocks.

GENERAL FEATURES AND STRUCTURAL RELATIONS.

Basaltic lavas and waterworn débris derived from them are interbedded in Miocene sediments on the south slope of the Chaîne des Mateux. About 4 or 5 kilometers north of l'Arcahaie, on the trail to Couyau, basalt is exposed in a ridge 50 to 60 meters in width and appears to be interbedded in the Miocene series. (See Fig. 5 and pp. 213-214.) Another exposure, which probably represents the same bed, was seen along the same trail, about 2 or 3 kilometers farther north.

Along the trail between Saut d'Eau and the Cul-de-Sac Plain, about 3 kilometers southeast of Source Morissel, conglomerate that consists probably of reworked basaltic agglomerates and tuffs is interbedded in the Miocene series.

PETROGRAPHY.

A fragment or cobble of dark-gray amygdaloidal lava in the Miocene sediments south of Saut d'Eau contains amygdules lined with chlorite and calcite.

In thin section this rock consists of abundant needles of labradorite and thin prisms and grains of augite in a somewhat altered base that contains chlorite. Greenish augite also forms phenocrysts from 0.2 to about 1 millimeter in diameter, partly in clusters of several grains. The thin prisms of augite, especially in the groundmass, have a brownish color and are zonal, giving an extinction $Z \wedge c$ ranging from 46° to 52°. Magnetite is an accessory mineral in small grains. Some aggregates of a serpentinous or chloritic mineral may be secondary after olivine, although their shapes are not distinctive. Chlorite occurs interstitially in the altered base and also lines some amygdules. Zeolites and calcite are also present in the amygdules. The augite, which forms 40 to 50 per cent of the base, is somewhat similar in character and development to the augite found in the nephelite basalts near Saut d'Eau and Maneville. This basalt is furthermore similar in many respects to the amygdaloidal basalts of the later basaltic eruptions of the northern region. (See p. 284.)

AGE AND RELATIONS OF THE LAVAS.

Conclusive evidence that the volcanic débris in the Miocene beds near Source Morissel was derived from lavas of Miocene age was not obtained. Some of the eruptions, however, probably occurred in Miocene time, as is indicated by the bed of solid basalt in the Miocene north of l'Arcahaie. (See Fig. 5, p. 128.)

SOUTHERN REGION.

General Features.

The igneous rocks of the southern part of the Republic are more uniform than those of the northern and central regions. So far as known, all are of extrusive origin or are parts of minor intrusive bodies associated with eruptions of lava. With the exception of small areas of andesitic rocks near Baradères the lavas are predominantly basalts. The largest area of these basaltic rocks is in the Massif de la Selle, where they are exposed on the crest of the major anticlinal arch. Smaller areas are exposed farther west, where the overlying Tertiary limestones have been removed by erosion.

With the possible exception of a minor occurrence of basalt that may be of Miocene age, a Cretaceous period of igneous activity is the only one that has been recognized in the southern region. The small zone of andesitic rocks near Baradères may not belong to the main period of basaltic eruptions, but as the andesites also underlie the upper Eocene limestone, the two periods of eruption probably were separated by only a relatively short interval.

Late Cretaceous Basaltic Rocks.

DISTRIBUTION AND STRUCTURAL RELATIONS.

Basaltic rocks, probably of late Cretaceous age, constitute most of the basement on which the Tertiary limestones were deposited in the southern part of the Republic. Their surface distribution is entirely dependent on later erosion. At many places the basalts are exposed only in small patches beneath the cover of Tertiary sediments. A number of the larger exposures are shown on the geologic map (Pl. I). Descriptions of the distribution and structural relations in the larger areas examined during the reconnaissance are given below.

Massif de la Selle.—In the Massif de la Selle the overlying upper Eocene limestone has been removed over an area from 500 to 600 square kilometers in extent. The major structure of the area is that of an eroded anticlinal arch, although this structure is modified by more or less extensive faulting. The northern boundary of the area, near Furcy, which is marked by a conspicuous scarp of limestone, appears to be a high-angle thrust fault. (See Fig. 20, *A*, p. 322.) At the southern boundary, along the Grande Rivière de Jacmel, the contact is also marked by a fault, upturned basal beds of Eocene limestone being in contact with massive basalt. (See Fig. 20, *B*.) The faulting at this locality appears to be normal. The basal beds of the upper Eocene limestone are clearly exposed along the Grande Rivière de Jacmel below the boundary between the basalt and the limestone. Near Furcy the upper part of the series is in contact with the basalt. The southeastern boundary of the area was not seen, except

from a distance, but it appears to be irregular, owing to high limestone ranges that jut into the area of basalt. At the southern boundary of the Léogane Plain, near the Rivière des Citronniers, basaltic agglomerate and breccia pass under the alluvial deposits. Farther east, along the Rivière Momance, the basaltic breccia and limestone seem to be in fault contact.

A small area of basalt is exposed on the south coast, on the west side of the small stream at Guillaumone. This basalt clearly underlies the upper Eocene limestone. An exposure on the slope leading down to the coast shows that the limestone was deposited on an irregular surface of the basalt.

A larger area of basalt lies back of the plain at Cayes de Jacmel. Impure tuffaceous limestones are interbedded with the basalts south of Étang Bossier. There is no basis for the supposition that Étang Bossier is a crater lake.

Near the base of the basalts in the Massif de la Selle are interbedded impure tuffaceous limestones and shaly rocks of marine origin, giving evidence of contemporaneous volcanic activity during their deposition. (See p. 95.) Patches of older sheared metamorphic limestones are engulfed in the basalts at several localities. (See p. 92.) Both the basalts and their associated tuffs and limestones are intricately folded.

Except for thin local beds or lenses the basalts are remarkably free from interbedded tuffs or other pyroclastic débris, although in the valley of the Rivière des Citronniers there are exposures of coarse volcanic breccias and tuffs, which appear to be of considerable extent and thickness. Whether these rocks are at the top or the bottom of the eruptive series was not definitely determined, although they probably are near the top.

The generalized sections in Figure 20, *A* and *B*, show the relations of the basalts and the associated limestones in the Massif de la Selle.

Étang de Miragoane.—Basalts are exposed in the depression occupied by the Étang de Miragoane. Along the road at the north side of the lake the basalts are overlain unconformably by basal beds of the upper Eocene limestone, consisting of fine conglomerates or sandstones and dark slates. The south side of the basin was not explored, but it consists of a straight and rather steep mountain front, the lower slopes of which may possibly be of volcanic rocks but the crest is composed of limestone. This mountain wall may be flank of an eroded anticline, the crest of which passes through the center of the depression occupied by the Étang de Miragoane.

Vicinity of Asile Valley.—Basaltic rocks associated in part with limestones, probably of upper Cretaceous age, are exposed along the Grande Rivière des Nippes and the Rivière Serpent. The structural relations of these limestones to the basalts indicate that they were deposited at the time of the earlier eruptions.

Pillow structure in basalt exposed north of the Grande-Rivière des Nippes on the trail to Anse-à-Veau shows that some of the flows were

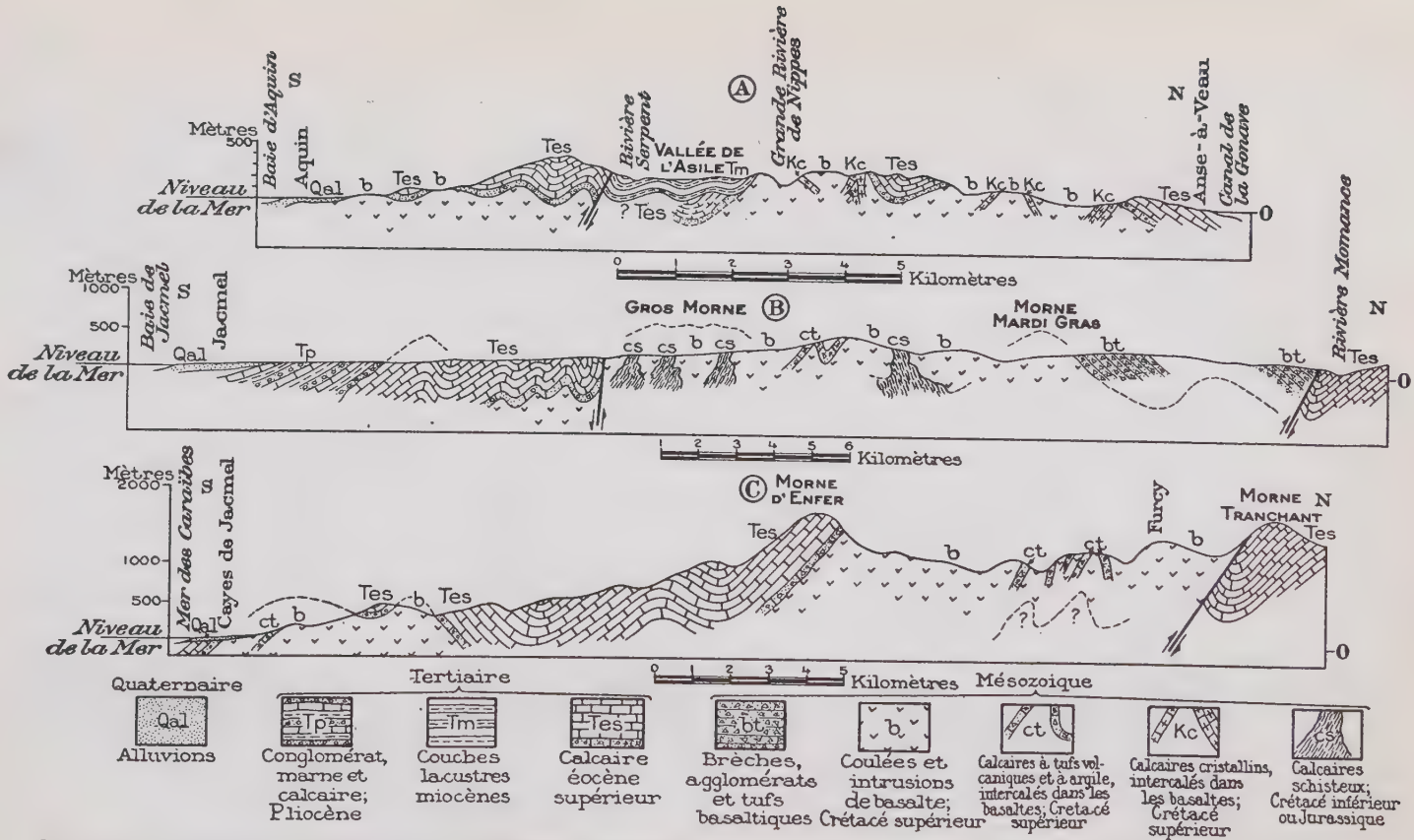


FIGURE 20.—Generalized sections across the Southern Peninsula showing the relations of the basaltic lavas and the sedimentary rocks.

A, Section from Aquin through the Asile Valley to Anse-à-Veau. *B*, Section from Jacmel to the Rivière Momance, southeast of the Léogane Plain. *C*, Section from Cayes de Jacmel to Morne Tranchant.

submarine and included fossiliferous calcareous mud similar to that which forms the more massive limestones. (See Plate VIII, *B*, and p. 96.) At other places the lavas have overflowed or buried more indurated calcareous deposits. The contacts at some places are parallel to the bedding planes of the limestones. Figure 20, *C*, is a generalized section which shows diagrammatically the relations of the upper Cretaceous (?) sedimentary rocks to the basalts.

Vicinity of Aquin and St. Louis du Sud.—Basalts crop out in some parts of the Aquin Plain and along its borders, where they are overlain by upper Eocene limestone. A few low hills between Aquin and Vieux Bourg consist largely of basalt, but their sides are strewn with limestone float, which probably comes from a cap of upper Eocene limestone. A good exposure in a road cut about 8 or 9 kilometers west of Aquin shows basalt overlain by brownish and greenish shales and impure limestone. Farther west along the coast, near St. Louis du Sud, the basalts form the lower parts of the mountain ranges, which are capped with massive limestones, and also form many of the coastal hills. The lower alluvial valleys of some of the rivers, such as that of the Rivière du Mesle, are underlain by basalts, although the bed rock is concealed in places by river deposits. East of St. Louis du Sud many of the basalts show pillow structure and weather into ellipsoidal or round boulders, which strew the ground. Basalt underlying the basal beds of the upper Eocene limestone is exposed on the trail from Cavaillon to St.-Louis, near the crest of the hill 6 or 7 kilometers southeast of Cavaillon.

Western part of peninsula.—North of Port-à-Piment the basaltic rocks occupy an east-west troughlike valley that separates the limestone mountains near the coast from the outskirts of the main range of the Massif de la Hotte to the north. From Les Anglais to Tiburon the low basalt ranges skirt the coast and a higher limestone range, which adjoins them to the north. Between Tiburon and Anse d'Ainhault basalt is the predominating rock of the foothills and low ridges along the coast, although here and there spurs of limestone extend to the coast. Limestone crops out on the crests of the higher ranges to the east.

Sources Chaudes.—The interior valley at the Sources Chaudes is in basaltic rocks, which are apparently overlain along the northern border by basal shaly beds of the upper Eocene limestone. The hot springs issue from fissures in the basalt along the south side of the valley.

PETROGRAPHY AND CHEMICAL COMPOSITION.

Basalts.—The normal basalts are dark-gray to black rocks, less commonly brownish gray or brown because of alteration. In texture they generally are aphanitic, but contain a few phenocrysts of plagioclase, augite, or olivine. Some of the rocks, particularly those in the central part of the peninsula, are amygdaloidal, and pillow structure is common everywhere. The amygdules generally are filled with chloritic minerals, chalcedony,

calcite, or zeolites, and a few contain pyrite. The blocks of the pillow lavas vary from subangular to smoothly ellipsoidal in outline and range in diameter from 8 or 10 centimeters to a meter or more. The spaces between the blocks may be occupied by secondary minerals or, less commonly, by sediments (Pl. VIII, *B*). Some of the more altered purplish-brown lavas are amygdular and have a banding or eutaxitic structure.

The black lavas weather at the surface to a brownish gray or rusty brown, and have rusty-brown films along the joint cracks. The pillow lavas weather into round cobbles or boulders that may strew the ground. They disintegrate by spalling off parallel to the surface.

In thin section the dark-gray aphanitic lavas generally are porphyritic, containing phenocrysts of basic plagioclase and less commonly of diopside or augite in a groundmass of intergranular texture, consisting of granules of augite interstitial to a plexus of thin plagioclase laths. (See Pl. XXIII, *A*, p. 316.) Many lavas contain a few phenocrysts of olivine.

The plagioclase phenocrysts are euhedral to subhedral prisms, generally from 0.2 to 2.0 millimeters in length, and comprise from 5 to 10 per cent of the rock volume. They differ in composition in different lavas but are either bytownite or labradorite when unaltered and are somewhat zonal. The more calcic plagioclase may have centers as calcic as Ab_{25} An_{75}, but most of the phenocrysts are calcic labradorite (Ab_{40} An_{60} to Ab_{35} An_{65}). The plagioclase may be partly in clusters of prisms. A few smaller phenocrysts of diopside or augite may be present, generally associated with the clusters of plagioclase.

Olivine is sparingly present as phenocrysts in many of the lavas but rarely comprises more than a small proportion of the rock. It generally is partly or completely altered to serpentine or iddingsite. Olivine or its alteration products comprise as much as 10 or 15 per cent of the rocks in only one or two specimens examined. Such rocks are olivine basalts.

The plagioclase of the groundmass is in thin subhedral to euhedral prisms, consisting mostly of labradorite (Ab_{40} An_{60}). They range in length from 0.05 to 0.5 millimeter. In many of the basalts the prisms are interlacing. In specimens containing a high percentage of augite or a partly glassy base, they may form only a very incomplete network. The plagioclase, including the phenocrysts, forms 30 to 45 per cent of the rock.

The pyroxene, which is the predominating constituent in most of the rocks, generally appears to be a variety of diopside but varies in different rocks ($\alpha=1.675$, $\beta=1.685$, $\gamma=1.70$–1.705). It is nearly colorless or slightly greenish to brownish, and except for a few scattered phenocrysts in some of the rocks is in small granules (0.05 millimeter) interstitial to the plagioclase. The diopside rarely occurs in grains large enough to inclose prisms of plagioclase. It forms 40 to 60 per cent of the rock.

Magnetite, probably titaniferous, occurs in small grains interstitial to the plagioclase or as larger grains of earlier crystallization. In some lavas

the iron ore is certainly largely ilmenite. The iron ores comprise from 5 to 10 or 12 per cent of the rock. A few grains of greenish to brownish accessory hornblende were noted in one rock.

Some rocks are coarser grained, containing pyroxene grains as much as a millimeter or more in diameter inclosing the plagioclase and producing a subophitic texture. The texture is in some places intersertal, with glass or alteration products occupying the spaces between the diopside or augite. A brownish to greenish micaceous mineral, resembling the serpentine that replaces some of the olivine, fills pores in the groundmass of some lavas.

A chemical analysis of a basalt from the Massif de la Selle, north of the Rivière Gosseline, and the average of a number of analyses of basalts for comparison are given in the following table:

Analysis of basalt from the Southern Peninsula of Haiti, and average analysis of basalt.

	1	2
SiO_2	48.97	48.78
Al_2O_3	14.90	15.85
Fe_2O_3	.96	5.37
FeO	10.27	6.34
MgO	7.09	6.03
CaO	11.72	8.91
Na_2O	2.06	3.18
K_2O	.33	1.63
H_2O+	1.35	1.76
H_2O-	.28	
TiO_2	2.05	1.39
P_2O_5	.24	.47
MnO	.15	.29
	100.37	

1. Basalt, Southern Peninsula of Haiti, Massif de la Selle north of the Rivière Gosseline, Republic of Haiti. H. S. Washington, analyst.

2. Average of 161 analyses of basalt. Daly, R. A., Igneous rocks and their origin, p. 27, 1914.

The mineral composition of the rock analyzed, as measured approximately by the Rosiwal method, and the norm, as calculated according to the quantitative classification, are as follows:

Approximate mineral composition and norm of basalt from the Southern Peninsula of Haiti.

Approximate mineral composition.		Norm.	
Labradorite	38.6	Orthoclase	1.84
Diopside	50.6	Albite	17.40
Olivine and serpentine	4.1	Anorthite	30.44
Ilmenite and magnetite	6.7	Diopside	21.51
		Hypersthene	20.60
		Olivine	1.09
		Ilmenite	3.88
		Magnetite	1.39
		Apatite	.57
		The rock is auvergnose (III.5.4.5).	

The basalt is notably high in lime and is rather high in titanium. The low ferric iron indicates that the iron ore is largely ilmenite.

Albitized or spilitic basalts.—Reddish-brown to gray lavas of amygdaloidal texture, in which the feldspars are largely albite, apparently of secondary and late magmatic origin, are found in the valley of the Rivière des Citronniers. The amygdules have a maximum diameter of 5 or 6 centimeters. They are filled with calcite, chlorite, or zeolites.

In thin section the rocks are porphyritic, containing phenocrysts of plagioclase and some of olivine in a groundmass of intergranular texture similar to that of the normal basalts. The plagioclase consists largely or entirely of albite. Their original texture and twinning lamallae are generally preserved, although in some rocks the plagioclase is recrystallized to a granular aggregate of albite. The olivine once present in some of the rocks is altered to iron oxides or chloritic minerals. The pyroxenes are rather fresh, although they may be partly replaced by chlorite. Chlorite and zeolites replace the plagioclase in some of the rocks.

The amygdules of the rocks consist of zeolites, chlorite, and calcite. The zeolites do not appear to correspond in optical properties to any described species. In some rocks zeolites (?) are the principal minerals in the amygdules. They form parallel or radial crystalline growths or hard fibrous growths resembling chalcedony. Some of the minerals are stained pinkish in places from impurities.

The optical properties of three minerals that are common in many of the lavas were determined as follows:

1. A colorless to translucent or whitish mineral forms parallel or radiating growths of prismatic plates. Fragments colorless. Optically +, 2V medium. Prismatic plates with Z normal to perfect cleavage and plates. Y is parallel to the prismatic cleavage and elongation. Crushed fragments tend to lie on a face that is normal to Z and that in convergent light shows an acute bisectrix.

$\alpha = 1.523 \pm 0.003$ $\beta = 1.524 \pm 0.003$ $\gamma = 1.536 \pm 0.003$.

2. Translucent to white or bluish fibrous platy mineral. Hardness 5 to 6. Fragments may be clouded with threadlike inclusions parallel to cleavage. Optically +, 2V large. Prismatic plates with Z normal to platy cleavage. X is parallel to fibers or prismatic cleavage. Crushed fragments tend to lie on a face that is normal to Z and that shows a positive bisectrix.

$\alpha = 1.508 \pm .003$. $\beta = 1.51 \pm .003$. $\gamma = 1.513 \pm .003$.

3. Whitish to bluish translucent mineral in tough fibrous growths. Hardness 6. Parallel fibers with parallel extinction and negative elongation. Birefringence very low ($.001 \pm$). $n = 1.52$ approximately.

Diabase porphyries.—Coarse-grained basaltic rocks containing large phenocrysts of plagioclase and some of augite were found at several places in the Massif de la Selle south of Furcy. The plagioclase phenocrysts,

consisting of labradorite and bytownite, range from a few millimeters to 1 centimeter in length and comprise 10 to 15 per cent of the rock. The phenocrysts are partly in starlike groups. The plagioclase phenocrysts in one of the specimens are considerably clouded with saussuritic aggregates and are replaced along cracks by chlorite. The texture of the groundmass of these rocks is subophitic. The grains of augite are about a millimeter in diameter and only partly wrap around the plagioclase in the groundmass. Besides platy titaniferous magnetite or ilmenite a few flakes of partly altered biotite occur as an accessory mineral. Pyrite is a secondary mineral in one specimen. Although the texture of these rocks is not typical of the coarse-grained diabases, they presumably are parts of minor intrusive bodies.

Basic augite andesites.—Rocks similar to the ordinary basalt in appearance and texture, but in which the plagioclase is predominantly andesine (Ab_{60} An_{40}), were found at a few places in the central part of the peninsula between Miragoane and Aquin. They contain no remnants of olivine and generally have some interstitial brown glassy base. The few specimens studied are considerably more altered than most of the basalts. Chlorite (delessite), calcite, and zeolites are abundant alteration products, replacing plagioclase and obscuring the texture of some of the rocks. Calcite and heulandite are associated in veinlets and replace the plagioclase. The plagioclase seems to be the first mineral to alter, the augite in some rocks remaining almost unaltered when the plagioclase is nearly destroyed.

ALTERATION.

The only extensive alteration products in the basalts are chlorite, zeolites, calcite, and serpentine. The chlorite, calcite, and zeolites form amygdules or line vesicles and may fill the spaces or replace the basalts around the blocks in pillar lavas. In some places the rock is almost completely replaced by these minerals. The plagioclase is the first mineral attacked in alterations of this type. The zeolites are analcite, heulandite, and several unidentified or undescribed species found in the albitized basalts along the Rivière des Citronniers. (See p. 326.) Heulandite is widespread and generally is intergrown with or accompanies calcite. In a few places pyrite accompanies analcite and calcite in amygdules. The presence of these alteration products only in the amygdules of some rocks or between the blocks of pillow lava indicates that they were formed during or shortly after the period of volcanic activity. They were presumably deposited from aqueous solutions expelled by the solidification of the lavas themselves or from similar solutions of extraneous origin and from hot springs associated with the volcanic activity. The complete alteration of some lavas probably was due to their position near volcanic centers or near conduits bearing such solutions.

The alteration of olivine to serpentine or iddingsite appears to be of slightly different character. This alteration may have taken place in rock

that is otherwise quite fresh. It probably occurred during or soon after the solidification of the lavas and was assisted only by the presence of a small amount of expelled water.

Local albitization and formation of zeolites and other minerals (?) was noted in the reddish amygdular lavas from the valley of the Rivière des Citronniers and in reddish amygdular lava from the Grande Rivière de Nippes. There appears to be little doubt as to the secondary origin of the albite in some of these rocks, although the augite is unaltered.

The basaltic lavas weather to hematite-bearing soil.

ORIGIN OF THE LAVAS.

The uniformity of the basalts over the greater part of the southern region and the general lack of extensive pyroclastic deposits indicate that they were erupted principally through fissures. A few small dikes, however, cut the basaltic rocks.

The large deposits of agglomerate and tuff along the north side of the Massif de la Selle south and east of the Léogane Plain may have been formed during a late period in the volcanic activity, as they are not near the base of the basalt series. These deposits must have been formed by explosive eruptions from central vents or volcanoes. It may be of some significance that the amygdaloidal albitized or spilitic lavas are found in the vicinity of the fragmental deposits in the valley of Rivière des Citronniers. During periods of relative quiet between periods of explosive activity the molten lava in the volcanic necks or conduits would be under conditions more favorable for the concentration of the light constituents than during the relatively quick eruptions that produced the fissure type of rocks. The concentration in the upper part of the magma chambers of the volatile and alkaline constituents would produce alkaline magmas yielding highly gaseous vesicular and amygdaloidal lavas and would cause the local albitization either of the lavas themselves or of the rocks adjacent to the volcanic vent.

The association of the lavas with limestones north of the Asile Valley, the presence of pillow structure in many of them, and the interbedding of calcareous shales and limestones in the lavas of the Massif de la Selle all seem to indicate that the eruptions took place at or near sea level and were sometimes interrupted by the deposition of material derived from them on flood plains or in the sea. Some of the flows were undoubtedly submarine, possibly the greater part of those that show pillow structure. Some of the submarine flows may not have pillow structure.

The centers from which the eruptions of the southern region took place are not known and in all probability were not confined to the present outlines of the peninsula, which were largely determined in late Tertiary time. The agglomerates and tuffs in the northwestern part of the Massif de la Selle probably are close to later centers of explosive activity.

AGE OF THE LAVAS.

As the lavas in the Massif de la Selle at Étang Bossier are interbedded with limestones containing fragments of supposed upper Cretaceous mollusks, a part of the eruptive rocks at this locality is probably of late Cretaceous age. (See p. 95.) Pillow lavas east of the Asile Valley along the Grande Rivière de Nippes are also associated with limestones which are probably of the same age. (See Pl. VIII, *B*.) The lavas both in the Massif de la Selle and at other places in the Southern Peninsula contain interbedded marine deposits, indicating that the eruptions took place at or near sea level, probably for the most part during Cretaceous time. Between Jacmel and Léogane the basalts have buried sheared limestones, which may be lower Cretaceous or older.

The periods of greatest igneous activity were probably in upper and possibly late middle Cretaceous time. Probably the activity ceased during the folding that took place in most parts of the Republic in very late Cretaceous time. No evidence of contemporaneous activity was found in any part of the basal upper Eocene of the Southern Peninsula.

ANDESITES.

DISTRIBUTION, STRUCTURAL RELATIONS, AND AGE.

Andesitic lavas were found only west of Baradères, where they underlie the upper Eocene limestone unconformably, like the basalts east of the town. Their relations to these basalts are unknown, but they may be minor flows or intrusive bodies of the same age as the Cretaceous basaltic eruptions. So far as known they are not interbedded with basalts. They extend from the vicinity of the Rivière Salée eastward to the Rivière du Baradères. Small areas may extend along the west side of the Baie des Baradères.

PETROGRAPHY.

Hypersthene andesites.—Gray or brown rocks of fine-grained porphyritic texture containing abundant plagioclase phenocrysts as much as 1 millimeter in length and scattered smaller prisms of altered hypersthene make up part of the andesites. One specimen showed fine platy partings or sheeting planes about 4 millimeters apart, probably genetically related to the contraction of the rock after solidification.

In thin section the sheeted lava consists of plagioclase phenocrysts, mostly in euhedral prisms from 0.2 to 1 millimeter in length, comprising about 50 per cent of the rock, in a fine-grained semicrystalline base. The plagioclase phenocrysts range from labradorite (Ab_{40} An_{60}) in the more calcic ones to calcic andesine and are strongly zonal. They probably average a calcic andesine or sodic labradorite (Ab_{50} $An_{50}\pm$) in composition. Bastite pseudomorphs after hypersthene are less abundant as phenocrysts, a few of them a millimeter in length. The groundmass consists mainly of small plagioclase prisms and microlites, prisms and microlites

of bastite, and some light-colored glassy base. A small amount of magnetite and numerous small apatite prisms are scattered in the groundmass. The rock is notably low in dark constituents.

Hornblende andesites.—Light-gray to brownish-gray porphyritic rocks containing plagioclase and hornblende phenocrysts in a fine-grained to felsitic groundmass form another variety of the andesites. Some of these andesites weather into round boulders that spall off in concentric zones. These boulders are stained on the outside with brown iron oxides.

In a thin section of a rock collected west of the Rivière des Baradères, the plagioclase phenocrysts form euhedral to subhedral laths, from 2 to 5 millimeters in length, and comprise about 15 to 20 per cent of the rock. The more calcic ones have centers of labradorite (Ab_{40} An_{60}), but most are andesine. Some are strongly zoned, ranging in composition from andesine (Ab_{55} An_{45}) to oligoclase (Ab_{65} An_{35}). The hornblende phenocrysts, as much as 4 or 5 millimeters in length, generally are completely resorbed, leaving a skeleton of magnetite or a granular aggregate of magnetite, pyroxene, plagioclase, and calcite. There are two generations of plagioclase in the groundmass, the later generation of small laths showing a trachytic texture. The plagioclase is sodic andesine or oligoclase (Ab_{65} An_{35} to Ab_{70} An_{30}) in composition. Magnetite and small brownish prisms of apatite are accessory minerals.

Post-Eocene (?) Basaltic Rocks.

Basaltic rocks underlying Pleistocene marine deposits crop out at the base of a prominent sea cliff about 5 kilometers northwest of Chardonnières. A bed of gravel several meters thick, composed of cobbles of the underlying basalt and of limestone, lies at the base of the Pleistocene marine deposits. The basalt itself contains large blocks of white limestone resembling Eocene limestone and blocks of brown metamorphic limestone. The relations suggest that the basalt may overlie the upper Eocene limestone exposed a few hundred meters to the southeast along the coast. As the Eocene age of the limestone fragments in the basalt has not been established the suggestion that the basalt is younger than Eocene is only tentative. No exposures of basalt known to be younger than Eocene have been recognized south of the Cul-de-Sac Plain. The Oligocene and Miocene basalts in the Chaîne des Mateux and Montagnes du Trou d'Eau are entirely different from any basalts found in the Southern Peninsula.

The basalt in the cliff near Chardonnières is mottled from greenish gray to red or black by weathering. It is thickly veined with calcite, part of it in crystals 10 to 15 centimeters in length. The lava is an ordinary basalt or an augite-rich andesite, as the plagioclase is labradorite and calcic andesine. The rock contains considerable augite, so that it appears to correspond in mineral composition to the Cretaceous basalts.

TECTONICS.

By Wendell P. Woodring.

General Features.

The relation of the West Indies to North America is somewhat similar to the relation of the Alps to Europe and of the Himalayas and East Indies to Asia. The West Indian region is a young mountainous complex, and its major tectonic features are due to crumpling of the earth's crust during the Alpine period of folding. It lies between the rigid mass of the Venezuelan highlands and the coastal plain of the southeastern United States, which, although covered in part by the Tertiary seas, was virtually rigid during the folding. During late Mesozoic and Tertiary time the West Indian region was part of the equatorial geosyncline that apparently almost completely encircled the globe. The track of this geosyncline is outlined by a zone of Alpine folds.

The tectonic trends of the Republic are shown in Plate XXIV. In the regions of broad folds these lines represent the crests of anticlines and the troughs of synclines, but in regions of closely spaced folds they merely represent the prevailing strike of the rocks. Some of the tectonic lines show the direction of major lines of rupture.

A striking feature of the tectonic lines, as shown by Plate XXIV, is their arrangement in arcs resembling the arcs of the geographic features, which the tectonic features have largely determined. No attempt has been made to discover the significance of the arrangement of these arcs, but they are like the arcs of folded mountains in other regions. Most of the arcs trend northwestward and are convex southward. In the Northwest Peninsula the west end of the arc representing the crest of the anticlinal arch formed at the end of Miocene time bends southwestward, thus paralleling the northeast end of the Bartlett Deep, which separates the islands of Haiti and Cuba and which at some places between them attains a depth of more than 1,000 fathoms. Some of the arcs in the Southern Peninsula are convex northward, and at the west end of the peninsula they seem to virgate, or branch out sheaf-like.

In this part as in other parts of the Tertiary equatorial geosyncline, beds that are no older than Pliocene, even Quaternary beds, are folded. Here also, as in other regions, the beds were folded at different times. There were apparently three principal periods of folding, one at the end of Cretaceous time, one at the end of Eocene time, and one during and at the end of Miocene time. Probably each of the periods of folding continued into the succeeding geologic period, and in parts of the Republic the folding that began in Miocene time still continues. A surprising result of the reconnaissance is the discovery that the tectonic features of

a large part of the Republic are due to folding and crumpling of the beds during the last period of folding—that is, during Miocene and Pliocene time.

Tectonic History.

The pre-Mesozoic and early Mesozoic tectonic history of Haiti is so obscure that it can not be deciphered from the information now available. The schistose limestones of Tortue Island and the float of similar intensely metamorphosed rocks seen on the North Plain and the Léogane Plain indicate a record of Paleozoic or early Mesozoic folding that is too fragmentary to read.

The most extensive beds of known or supposed Cretaceous age are in the Massif du Nord. These beds are everywhere complexly folded. In the eastern part of the massif their strike is to the northwest, but in the western part it bends around toward the north, thus forming arcs that are convex to the south. Beds in the northwestern part of the Montagnes Noires and in the Southern Peninsula that are considered of the same age are similarly folded. This folding probably took place at the end of Cretaceous time, although its results can not easily be distinguished from those of later folding. For this reason no age can be fixed for some of the tectonic lines shown on Plate XXIV. The folding was accompanied or followed by intrusions of relatively large batholiths and stocks of quartz diorite, which reach the surface only in the northern part of the Republic and probably were confined to that part. The eastern part of the Massif du Nord contains the largest exposed batholith, and this same region was rigid after the intrusion. This rigidity presents a marked contrast to the mobility that prevails in the central part of the Republic, where thick deposits of younger marine sedimentary rocks have been considerably folded and crumpled.

Beds of marine limestone of upper Eocene age are the most widespread surface rocks in the Republic, as is shown by the geologic map (Pl. I) and the descriptions on pages 106-138. These beds are folded and crumpled, in some areas more complexly folded than the younger rocks, so that there may have been a period of folding at the end of Eocene time and in early Oligocene time. It is difficult to distinguish the results of this period of folding from the results of the folding at the end of Miocene time. In the northwestern part of the Montagnes Noires, where there are no Miocene rocks, the trend of the folds is the same as in the southeastern part, where Miocene beds are involved in the folding. In several parts of the Southern Peninsula the Eocene beds have been folded since Miocene time. The large basalt area south of Port-au-Prince seems to be on the crest of a broad anticlinal arch, which probably dates back to the end of Eocene time. The thrust faulting along the north side of the area of basalt may be later. (See fig. 20, *C*.) The wide distribution of folded upper Eocene beds gives the impression that the results of the folding that

occurred at the end of Eocene time are extensive, but the impression is probably misleading. In the mobile central part of the Republic, where there are extensive areas of Miocene rocks, the Oligocene and Miocene beds have the same strike and dip as the Eocene beds. In the southwestern part of the Northwest Peninsula, however, beds apparently of upper Eocene age strike north-northwestward, whereas the crest of the main anticlinal arch formed at the end of Miocene time trends west-southwestward. Some of the folding in the Montagnes de Terre-Neuve and in the mountains in the central part of the peninsula (Montagnes du Nord-ouest) probably took place at the end of Eocene time. The folds in the upper Eocene beds along the northern and southern borders of the Massif du Nord are probably of the same age. The Eocene beds extending across the crest of the Massif du Nord near Dondon and Christophe's Citadelle were apparently deposited in a trough diagonal to the trend of the Cretaceous rocks. Meager evidence indicates that the beds in this trough were folded at the end of Eocene time along lines diagonal to the older trends. There is no evidence that Eocene deposits formerly extended across the crest of the massif east or west of this trough. The folds in the northwestern part of the Montagnes Noires, as well as those in part of the interior of the Southern Peninsula, may also date back to the close of Eocene time.

The evidence available indicates that there was no folding during Oligocene time or at its end, but the post-Eocene folding may have continued into lower Oligocene time. Upper Oligocene deposits are apparently conformable with middle Oligocene, and Miocene beds rest conformably on upper Oligocene.

Considered in relation to the present morphology, the most important occurrence in the tectonic history of the Republic was the folding and crumpling of the rocks during Miocene and Pliocene time. The tectonic features of the entire mobile central part of the Republic, as well as the outlines of the Northwest Peninsula and of parts of the Southern Peninsula are the results of this folding. The Central Plain, Artibonite Valley, and Cul-de-Sac Plain are deep synclinal troughs; the Northwest Peninsula, Montagnes Noires, Chaîne des Mateux, and Gonave Island are anticlinal arches. Miocene rocks are involved in all of these folds.

The Miocene beds of the Northwest Peninsula seem to be arched in a broad anticline trending west-southwest. Miocene marl crops out under the cover of Quaternary limestone near the crest of the arch along Rivière du Môle. Evidence presented on page 159 indicates that the Miocene beds in the reentrants near the head of Rivière de Jean Rabel and Rivière Cadet on the north side of the peninsula are in a shallow synclinal trough diagonal to the general trend of the arch but parallel to the strike of the upper Eocene rocks farther west. The syncline may be a survival from an older structural feature in the upper Eocene rocks flanking the trough. The reentrant of Oligocene and Miocene rocks on the south side of the

same gap and the similar reentrants heading into the gap separating the Montagnes du Nord-ouest from the Montagnes de Terre-Neuve may be similar structural features. Along the east side of the Arbre Plain the strike of the Miocene beds parallels the Montagnes de Terre Neuve. Some of the folding in the Montagnes de Terre Neuve and in the Montagnes du Nord-ouest probably took place at the close of Miocene time. In the Montagnes de Terre-Neuve the folding was accompanied or followed by intrusions of quartz diorite and granodiorite.

The upper Oligocene or Miocene limestone covering most of Tortue Island seems to be arched in a broad anticline.

The sections on Plate XXXVI show that the Miocene rocks of the Central Plain are folded in a deep syncline and that they are upturned against the mountains along the borders of the plain. Near the foot of the Montagnes Noires in the northwestern part of the plain the lower part of the Thomonde formation is thrust northeastward over the Maïssade tongue (see Pl. XXXVI, section *B-B'*), and there is probably another high angle thrust fault of greater displacement at the mountain front. The northeast limbs of the Thomonde and Chamouscadille anticlines are very steeply tilted near the mountains, and in depth these folds probably pass into thrust faults. The great scarp south of Cerca-la-Source, near the southern border of the Massif du Nord (see Pl. XXV, *A*), seems to be a fault scarp between upper Oligocene limestone and Cretaceous (?) argillite, but the evidence available to prove the existence of this fault is stratigraphic only.

Northwest of the gorge of Rivière Artibonite the Montagnes Noires constitute a compound anticline, but southeast of the gorge they constitute a single anticlinal arch separated from the compound anticline by a syncline.

Figure 12, page 207, and Figure 13, page 208, show that the Artibonite Valley is a deep synclinal trough resembling the Central Plain and containing secondary anticlines. Exposures along the road from Mirebalais to Las Cahobas show that the Miocene rocks are crumpled near the foot of the Montagnes Noires. Plate XXVI, *A*, is a view of a small, peculiar asymmetrical anticline that extends across the narrow valley of Rivière Fer-à-Cheval at Savanette and, on the south side of the stream, bends eastward up the valley. West of Savannette a low arch almost at right angles to the trend of the trough of the syncline brings upper Oligocene limestone to the surface.

The Chaîne des Mateux is perhaps the most perfect example of a large anticline in the Republic. Figure 5, page 128, a section across the range, shows that on the southwest flank Oligocene rocks are thrust southwestward over Miocene rocks and that there probably is another thrust fault at the edge of the Arcahaie Plain. The secondary anticline on the northeast flank of the mountains near St.-Marc is shown in Figure 12, page 207.

A. SUPPOSED FAULT SCARP SOUTHWEST OF CERCA-LA-SOURCE.

The ridge is composed of limestone forming steep cliffy slopes. Part of the village of Cerca-la-Source is shown in the foreground.

B. FAULT SCARP ON THE EAST SIDE OF THE GONAÏVES PLAIN.

The trough of the Cul-de-Sac Plain is perhaps the most remarkable surface feature of the Republic. It has been interpreted as a downfaulted block bounded by normal faults and has been cited as a subaerial form of trough of the sort that is generally submerged in the West Indies, such as the Bartlett Deep, Brownson Deep, and Anegada trough. The Cul-de-Sac trough is clearly a syncline, as Miocene beds are upturned on the flanks of the mountains bordering it and similar beds have been penetrated by wells in the plain. Moreover, the trough is bounded on the south side by a zone of high-angle thrust faults that dip toward the mountains, and there is evidence on the north side of similar high-angle thrust faults. Figure 21 is a section drawn across the trough and part of the bordering mountains. (See also Fig. 15, p. 219.) The Eocene and Miocene rocks are more intricately crumpled than is shown in the figure. The main fault on the south side of the trough is well exposed on the Grande Rivière du Cul-de-Sac a short distance above Bassin Général. Steep southward dips

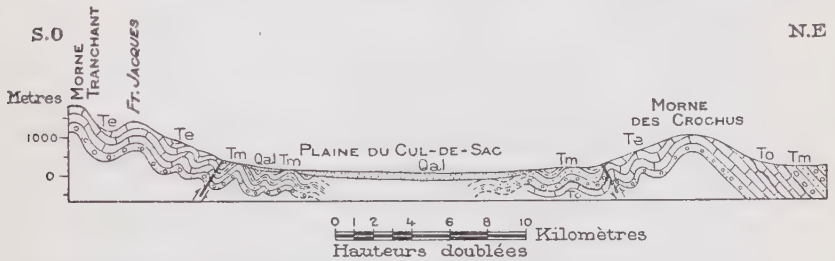


FIGURE 21.—Section across the Cul-de-Sac trough and adjoining mountains. Qal, Quaternary alluvium; Tm, Miocene; To, Oligocene limestone; Te, upper Eocene limestone.

were found on the north limb of the overturned arch south of the main fault. Plate XXVI, *B*, shows minor imbricated high-angle thrust faults exposed on the Grande Rivière du Cul-de-Sac in a zone of crumpled upper Eocene rocks south of the main fault. Port-au-Prince Bay and the St.-Marc Canal are apparently the submerged prolongation of this trough, which thus trends northwestward in an arc convex southward, parallel to the arcs of the Chaîne des Mateux, the Artibonite Valley, the Montagnes Noires, and the Central Plain.

The tectonic features of several parts of the Southern Peninsula clearly show that the widespread upper Eocene limestones were folded during Miocene time. Marine Miocene beds in the interior lowland on the Grande Rivière de Jérémie are now separated from the sea by a range composed of upper Eocene limestone. As shown on page 227 and in Figure 7 (p. 137), these Miocene rocks are not folded to form a synclinal trough but dip persistently northward toward the mountains, indicating that the upper Eocene limestone has been thrust southward over the Miocene beds. Lignite-bearing Miocene rocks at Camp Perrin are thrust northward over coarse conglomerates deposited as deltas and alluvial fans near the lakes

and swamps where the lignite-bearing beds were laid down. (See pp. 235-236, and Fig. 17, p. 234.) These nonmarine beds were probably at one time continuous with the marine Miocene beds that crop out on the Cayes Plain. The range of upper Eocene limestone now separating them may also have been thrust northward. Although the tectonic features of the largest interior lowland, the Asile Valley, are not fully known, it seems probable that a fault bounds the lowland on the south. Most of the nonmarine Miocene beds in this lowland are but slightly folded.

Gonave Island is a broad anticlinal arch. The trend of its crest parallels the Chaîne des Mateux and the folds in the northern part of the Massif de la Selle. Tilted Miocene beds cover the lower part of the flanks of the arch, and in the northwestern part of the island these beds extend across the crest.

All the Miocene rocks involved in the folding seem to be of lower and middle Miocene age. The folding probably began in late Miocene time. The evidence already given (see p. 241) shows that the marine conglomerates and marls in the valley of Rivière Gauche near Jacmel are of Pliocene age. These rocks are as strongly folded as any of the Miocene beds, so the folding must have continued into Pliocene time. The Pliocene beds strike northwestward and at all the localities where they were examined dip southwestward. The southern margin of the lowland was not examined, but if the southwestward dip continues it may be inferred that the upper Eocene limestone in the range bordering the lowland has been thrust northward. The same relation is suggested by the discovery that there are middle Oligocene rocks at sea level on the west side of Jacmel Bay and upper Eocene rocks at a higher altitude not far to the west.

Many high-angle thrust faults are associated with the folds, particularly those that were formed during the last period of folding. No extensive overthrust sheets such as characterize Alpine folds in many other parts of the Tertiary equatorial geosyncline were discovered. Detailed work among the upper Eocene limestones, which consist of many different types of rock, may reveal overthrust sheets.

The remarkable normal faults along the Trois Rivières trough are probably later than Miocene. The rocks in the trough are of middle and upper Oligocene age. Details of the fault along the west side of the trough south of Gros-Morne are given on pages 120-121, and the fault is shown in the section forming Figure 27, *A-A'* (p. 442), and Figure 30 (p. 471). The fault plane seems to dip steeply eastward, and the throw is several hundred meters. Normal faults of this magnitude are unusual in the Republic. The fault along the east side of the trough was not closely examined. The scarp that along its southward prolongation rises abruptly above the Gonaïves Plain is shown in Plate XXV, *B*. Morne Grammont, an outlier of the Montagnes Noires in this region, resembles the main mountain front, as it seems to be a block tilted northeastward and bounded on the west by a normal fault.

A. ASYMMETRICAL ANTICLINE OF MIOCENE MARL AND LIMESTONE AT SAVANETTE, ON RIVIÈRE FER-À-CHEVAL.

B. MINOR HIGH-ANGLE THRUST FAULT IN LIMESTONE OF SUPPOSED UPPER EOCENE AGE ON GRANDE RIVIÈRE DU CUL-DE-SAC.

In the mobile central part of the Republic and in the Northwest Peninsula the distribution of the Quaternary reef caps [1] is intimately related to the major folds produced during the Miocene folding. In these parts of the Republic the reef caps are confined almost entirely to the flanks and plunging crests of anticlines. This relation is shown by the reef caps on the crests and flanks of the northwestward-plunging anticlines north and south of St.-Marc but is most strikingly shown in the Northwest Peninsula, where the Quaternary reef caps have an altitude of 400 to 450 meters above sea level on the crest of the anticline formed during the Miocene folding. The reef caps are most numerous at the crest of the arch but decrease in number and altitude down on the flanks, away from the end of the peninsula. Gonave Island is the only major anticline striking into the sea on which reef caps were not found, but the extremities of the island were not examined and the caps may be there. So far as known all the reef caps are symmetrically arched over the anticlines. This arching of the reef caps shows that the folding in places continued through Quaternary time. In the Northwest Peninsula, at least, it is probably still going on. The significance of the distribution of the reef caps in the southern Peninsula is not known.

Bearing of Tectonics on Geologic History of West Indies.

The folding at the close of Miocene time determined the location of such geographic features as the Central Plain, Artibonite Valley, and Cul-de-Sac Plain, which if submerged would be similar on a small scale to the great submerged troughs of the West Indies. The Cul-de-Sac Plain would be a particularly striking trough if submerged, comparable to the Anegada trough and having about the same curvature. Accumulating evidence indicates that the submerged troughs were at least deepened if not entirely formed at the close of Miocene and during Pliocene time.[2] The Northwest Peninsula, which was the most mobile part of the Republic during Quaternary time, is adjacent to the northeast end of the Bartlett Deep, perhaps the most remarkable of the submerged troughs. The submerged troughs, which have been recently described by Taber,[3] have been interpreted by Vaughan and Taber as downfaulted blocks bounded by normal faults. The subaerial troughs are deep synclines bounded in part by a zone of imbricated high-angle thrust faults. It has recently been suggested that it is more reasonable to believe that the submerged troughs are similar deep synclines [4] probably limited by high-angle

[1] The Quaternary limestones at many localities resemble material in the near-by living fringing reefs; at other localities they are merely coralliferous limestones. For convenience all these deposits are called reef caps.

[2] See Vaughan, T. W., Geol. Soc. America Bull., vol. 29, pp. 625-627, 1918; U. S. Nat. Mus. Bull. 103, pp. 609-610, 1919.

[3] Taber, S., The great fault troughs of the Antilles: Jour. Geology, vol. 30, pp. 89-114, Pl. 1, text fig. 1, 1922.

[4] See Woodring, W. P., Tectonic features of the Republic of Haiti and their bearing on the geologic history of the West Indies (abstract): Washington Acad. Sci. Jour. (Awaiting publication.)

thrust faults. Possibly both the subaerial and the submerged troughs were deepened by vertical movements later than the folding, probably of the same age as the movements that produced the high-angle normal faults at the edge of the Trois Rivières Valley trough. This narrow trough would be a striking feature if submerged, but such troughs bounded by normal faults are unusual in the Republic.

EARTHQUAKES.

By Wendell P. Woodring.

Records Available.

Earthquakes are frequent in the Republic, as in other parts of the Tertiary equatorial geosyncline. During the history of the colony and of the Republic disastrous earthquakes have at times almost or completely destroyed Port-au-Prince, Cap-Haïtien, and other cities. Different parts of the Republic have had distinct seismic histories, and an attempt is here made to correlate the seismic phenomena with the known tectonic features. The information on which this attempt is based was obtained from records and accounts published by Rev. J. Scherer, Directeur de l'Observatoire Météorologique du Séminaire-Collège St.-Martial, Port-au-Prince. M. Scherer deserves the highest praise for his patience in collecting records and for his striking accounts of the disastrous shocks and of their relation to the surface and to the geologic features. His publications are as follows:

Les grands tremblements de terre dans l'île d'Haïti: Observatoire Météorologique du Séminaire-Collège St.-Martial Bull. semest., July-Dec., 1911, pp. 153-162, 1912. An English translation of this article was published in the Bulletin of the Seismological Society of America, vol. 2, pp. 161-180, map, 1912.

Les tremblements de Terre de l'île d'Haïti dans leurs rapports avec le relief du sol et les fosses maritimes qui l'entourent: Observatoire Météorologique du Séminaire-Collège St.-Martial Bull. semest., July-Dec., 1912, pp. 132-139, 1913.

Catalogue chronologique des tremblements de terre ressentis dans l'île d'Haïti de 1551 à 1900: Observatoire Météorologique du Séminaire-Collège St.-Martial Bull. semest., July-Dec., 1913, pp. 147-151, 1914. This catalogue is based principally on the following two catalogues: Poey y Aguirre, Andrès, Catalogue chronologique des tremblements de terre ressentis dans les Indies Occidentals de 1530 a 1858; suivi d'une bibliographie séismique concernant les travaux relatifs au tremblements de terre des Antilles: (Extrait de l'annuaire de la Société Météorologique de France, tome 5, p. 75, séance du 12 Mai, 1857) 76 pp., Versailles, 1858; and Tippenhauer, L. Gentil, Liste der Erdbeben auf Haiti: Die Insel Haiti, pp. 170-175, Leipzig, 1893.

Tremblements de terre observés en Haïti de l'année 1901-1910: Observatoire Météorologique du Séminaire-Collège St.-Martial Bull. ann., année 1920, pp. 100-104, 1921.

In addition to these accounts and catalogues, M. Scherer has published records of shocks in the Bulletins of the Observatoire. The Bulletins appeared semiannually from the last half of 1909 to the end of 1916, and

annually since 1917. The records are based on observations made by M. Scherer in Port-au-Prince and by correspondents at twenty-three other localities, namely: Cap-Haïtien, Borgne, Port-de-Paix, Bassin-Bleu, Gros-Morne, Môle St.-Nicolas, St.-Michel de l'Atalaye, Pilate, Gonaïves, Mirebalais, St.-Marc, Thomazeau, Gantier, Fond-Verrettes, Petionville, Furcy, Petit-Goave, Anse-à-Veau, Jérémie, Tiburon, Cayes, Bainet and Jacmel.

This list is based on the list of stations published in the bulletin for 1921, which is the latest bulletin now available. At times records were kept at Grande-Rivière du Nord, Bahon, Dondon, Bayeux, l'Arcahaie, Miragoâne, Dame-Marie, and Chardonnières.

Beginning with the bulletin of July-December, 1911, the records of a seismograph installed at the Observatoire have been published. The seismograph is the Omori-Bosch horizontal pendulum type, recording southeast-northwest and southwest-northeast movements magnified 40 times. This instrument is very useful in registering distant shocks, but it is useless for determining the direction and amplitude of local shocks. There is an immediate need in Haiti for instruments designed to register local shocks. Such instruments should be installed first at Port-au-Prince and Cape-Haïtien, and later at other places, particularly Môle St.-Nicolas and Anse-à-Veau.

The analysis of the seismic phenomena is divided into two parts, as the records gathered from different parts of the Republic by M. Scherer since 1909 are much more detailed than the records before 1909. Shocks that originated in the Dominican Republic or elsewhere are not considered.

Disastrous Earthquakes from 1551 to 1908.

During the early colonial period (1630-1750), after the French and English buccaneers had driven out the first Spanish settlers, the principal towns were on Tortue Island, along the north coast, at Petit-Goave, near the present site of Léogane (founded in 1712), and at St.-Louis du Sud. During the late colonial period (1750-1803), Cap-Haïtien was the largest city, but Port-au-Prince was already established and the present cities and towns grew gradually.

During the colonial period and the early period of the Republic only earthquakes that affected the administration of the government or the means of livelihood of the people were recorded. Even in such records only the destruction in the larger cities would be noted. Masonry and brick buildings, whose destruction during earthquake shocks causes the greatest havoc, are most numerous in the cities, and many of the larger cities are built wholly or in part on alluvium, which is more susceptible to the effect of shocks than bed rock or residual soil, particularly where ground water is near the surface. For these reasons, as Scherer has pointed out, records of the effects produced in the cities and in the more thickly populated alluvial plains, where the destruction was greatest, are the only

records that have come down to us. Little is known of the intensity of even the most disastrous shocks in the hilly country districts. But as cities were widely distributed even in the late colonial period, the intensity of disastrous earthquakes as indicated by their effects in the cities may be safely used in determining their origin. Moreover, the results of a study of the records of the disastrous shocks from 1551 to 1908 agree closely with the results of a study of the more complete records from 1909 to 1922.

From 1551 to 1908 there were seven disastrous earthquakes that apparently originated in the Republic of Haiti or under the sea near its shores. Many less severe shocks were recorded, most of them in the large cities, particularly in Port-au-Prince, but the records are of no value in determining the places of their origin.

On May 7, 1842, Cap-Haïtien, Port-de-Paix, and Môle St.-Nicolas were completely destroyed by the most disastrous earthquake recorded along the north coast. Cap-Haïtien was then and had been during the colonial period the most beautiful city in the Republic, and the accounts of the destruction there are most complete. It is estimated that 5,000 people were killed at the Cap out of a total population of 10,000. Most of the city stood on alluvium close to its contact with bed rock. The only record of a sea wave is that the sea dashed against the buildings along the quay. At Port-de-Paix not a single building remained standing after the shock. The sea withdrew 200 feet and then returned, covering the city with more than 15 feet of water. Probably most of the city stood on alluvium. Môle St.-Nicolas was an important military post, but the shock ruined the warehouses, forts, church, and aqueducts. There seems to be no definite record of a sea wave here, although in his catalogue Scherer records a wave along the entire Atlantic coast. Probably the entire town, except the fortifications, was built on alluvium. The destruction was great in the area extending eastward along the North Plain to and beyond the Dominican border. At Gonaïves and St.-Marc the shock was much less severe, although several houses fell. In the Southern Peninsula the shock was slight.

These records show that the shock was most severe along the north coast from Môle St.-Nicolas eastward to Cap-Haïtien. The recording of the sea wave only at Port-de-Paix may indicate that Port-de-Paix is near the place of origin, or the records may be deficient. The Bartlett Deep, as limited by the 1,000 fathom line, begins north of the Northwest Peninsula of the Republic and plunges sharply southwestward, parallel to the similarly plunging anticlinal crest of the Northwest Peninsula. It has been suggested on page 337 that the Bartlett Deep and other submerged deeps of the West Indies are synclinal troughs bounded by zones of high-angle thrust faults. The earthquake of May 7, 1842, was probably due to almost vertical displacement of the sea bottom along the fault zone at the south edge of the Bartlett Deep off the coast of the Northwest Peninsula.

This interpretation has already been given by Taber,[1] who claims, however, that the Bartlett Deep is a downfaulted block, bounded by normal faults. There is no evidence to substantiate the claim made by both Scherer and Taber that a prolongation of the Bartlett Deep extends along the channel south of Tortue Island and thence southeastward across the Cibao Valley of the Dominican Republic.

On September 23, 1887, another severe earthquake shook the same region. The destruction was greatest at Môle St.-Nicolas, where nearly all the houses were ruined. The sea withdrew a great distance and in returning augmented the disaster. At Port-de-Paix the recently erected church was destroyed. Farther east and south the destruction was not so great, but the sea wave was recorded as far west as Jérémie and Anse d'Hainault. The intensity of the shock and the size of the great sea wave at Môle St.-Nicolas indicate that this earthquake was due to almost vertical displacement along the south edge of the Bartlett Deep, probably farther southwest than the displacement that caused the earthquake of 1842, as Taber[2] has suggested.

No disastrous shocks are recorded in the central part of the Republic between 1551 and 1908. During the colonial period and the early years of the Republic the Central Plain and adjoining parts of the Massif du Nord belonged to the Spanish colony.

During the same period (1551 to 1908) there were several severe earthquakes in the southern part of the Republic, most of them centering near Port-au-Prince. The earliest shock occurred on November 9, 1701, when houses on the Léogane Plain were destroyed. The road from Léogane to Petit-Goave sank into the sea at places, but this movement may have been due to slumping. The records are too meager to show the place of origin of this shock. Port-au-Prince had not been founded at that time and the neighboring regions were thinly populated.

On November 21, 1751, Port-au-Prince suffered one of its greatest disasters from an earthquake. The newly founded capital then consisted of about 100 buildings, most of which were constructed of masonry. It is said that only one building was left standing after the shock and that it was destroyed by equally severe shocks on the following day. There were numerous aftershocks, and the people lived in tents until December 8. Probably all the buildings at that time, except the fortifications, stood on the low alluvial ground near the shore. In the Cul-de-Sac Plain, which is almost wholly covered with alluvium, many plantation buildings were laid in ruins. The shocks were felt at Léogane, St.-Marc, Gonaïves, and the Cap, but apparently the destruction was confined to Port-au-Prince

[1] Taber, Stephen, The great fault troughs of the Antilles: Jour. Geology, vol. 30, p. 102, 1922. Since this account was written Prof. Taber has published another paper describing the disastrous earthquakes of the Republic (The seismic belt in the Greater Antilles: Seismological Soc. America Bull., vol. 12, pp. 199-219, pl. 7, 1922). The conclusions regarding the origin of these shocks are the same as those given in the earlier paper.

[2] Idem.

and the Cul-de-Sac Plain. The field work done during the reconnaissance revealed a zone of imbricated high-angle thrust faults along the south side of the Cul-de-Sac trough. Some of these faults are well exposed on the Grande-Rivière du Cul-de-Sac above Bassin Général. Overturned folds, some of which are ruptured along high-angle thrust faults, were discovered closer to Port-au-Prince (see p. 130). The probable westward prolongation of this zone of overturned folds and faults is concealed near Port-au-Prince by nonmarine conglomerates, probably of Pleistocene age. Most of the folding and presumably of the thrust faulting took place at the end of Miocene and during Pliocene time. The region was mobile even later, as the Cul-de-Sac trough was completely submerged in Quaternary time. The earthquake of 1751, which was so disastrous to Port-au-Prince, was probably due to movements along one of the fractures in this fault zone. If the shocks were due to vertical or nearly vertical submarine movements, as the earthquakes of 1842 and 1887 were supposed to be, there would surely be some record of a sea wave, as the coast from the site of the city northward along the Cul-de-Sac Plain is very low.

Only 19 years later, on June 3, 1770, Port-au-Prince and the Cul-de-Sac Plain suffered another disaster, caused by one of the most severe earthquakes that has occurred since the island was settled by Europeans. The region of greatest destruction extended from Croix-des-Bouquets westward through the Cul-de-Sac Plain to Port-au-Prince and thence westward along the coast through Léogane and Petit-Goave to Miragoâne. Two hundred people were killed in the capital. Léogane was destroyed and only one building remained standing in Petit-Goave. The houses between Petit-Goave and Étang de Miragoâne were thrown down in ruins, even those that had been built on other than alluvial ground. The shock was felt all over the colony. Southey [1] states that the sea rose a league and a half up into the island, but this exaggerated report is not confirmed in contemporary accounts. At Grand-Goave part of the foot of a hill called La Saline was submerged, and " something similar happened in part of l'Arcahaie.[2] " This movement may have been due to slumping. If there had been a great sea wave it would be recorded, for all the towns destroyed along the coast were so situated that they would have been at least partly inundated. In the absence of authentic reports of a sea wave it seems reasonable to believe that this disastrous shock also had its origin in the fault zone along the south side of the Cul-de-Sac trough. Its intensity was apparently greater than that of the shock of 1751 and the area of destruction was greater along the thickly populated coast west of Port-au-Prince.

The coast from Petit-Goave to Anse-à-Veau had a moderately severe shock on April 8, 1860. At Anse-à-Veau the people sought refuge in La

[1] Southey, Captain Thomas, Chronological history of the West Indies, vol. 2, p. 407, London, 1827.

[2] Scherer, J., Les grands tremblements de terre dans l'île d'Haïti: Observatoire Météorologique du Séminaire-College St.-Martial Bull. semest., July-Dec., 1911, p. 161, 1912.

Haute Ville, the eastern part of the town, which stands on a Quaternary reef cap about 10 meters higher than La Basse Ville, the western part, which is built on alluvium. The sea withdrew and then broke on the shore with a crash. The shock did some damage as far west as Baradères, but was only slight at Jérémie. It was pronounced on the south coast at Aquin and Les Cayes, and even at Port-Salut. The damage in Port-au-Prince was only slight. The sea wave was not a prominent feature, as no wave is recorded at coast towns other than Anse-à-Veau. Moreover, the shock was much stronger on the south coast than on the north coast. Although the evidence is conflicting it seems that this shock originated in the Southern Peninsula. The tectonic features of the Asile Valley are not fully known, but the abrupt mountain slope along the south side of the valley seems to be a fault scarp, along which the principal movement took place after the close of Miocene time. (See Fig. 20, *A*, p. 322.) Con-

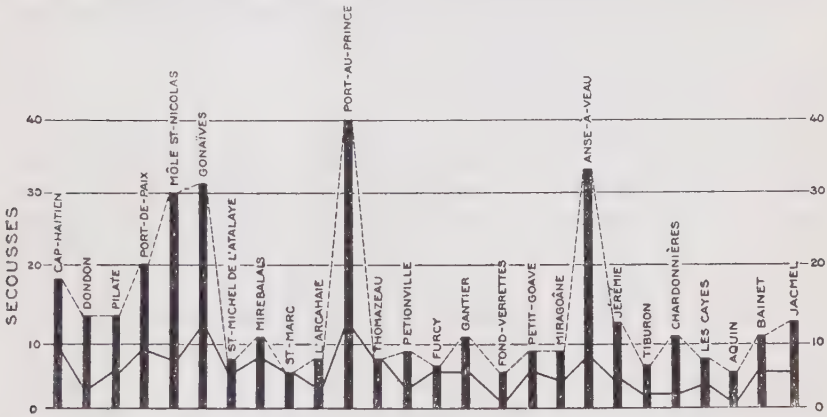


FIGURE 22.—Graph showing the number of earthquakes recorded at different stations from 1909 to 1922.

Lower curve (solid) represents general earthquakes felt in almost the entire country.

tinued movements along this supposed fault may account for the shock of 1860 and many later less serious shocks.

Taber[1] believed that the shocks of 1701, 1751, 1770, and 1860 were due to movements of the sea bottom off the north coast of the Southern Peninsula along a supposed fault zone extending westward from the Cul-de-Sac trough. The description on pages 397-398 clearly shows that the submerged prolongation of the Cul-de-Sac trough bends northwestward into the St.-Marc Canal. Although the off-shore slope along the western half of the Southern Peninsula is very steep there is hardly enough evidence to warrant the supposition of faulting, and the seismic phenomena can be interpreted otherwise.

EARTHQUAKES FROM 1909 TO 1922.

Figure 22 graphically shows the number of shocks recorded by Scherer and his correspondents from 1909 to May 4, 1922, inclusive. This graph

[1] Op. cit., pp. 94-95, 1922.

can not be rigidly used to show the frequency of earthquakes in different parts of the Republic, for the records of the observations on which it is based were furnished by as many different persons as there are localities. At some of the stations, Aquin for example, records were not kept continuously during the period covered. The completeness of the record at Port-au-Prince, which includes a large number of shocks, is probably due in part to the unfailing energy of M. Scherer. The lower line of the graph, representing the number of general shocks, would be smoother in some parts if all the general shocks were accurately recorded during the entire period at the different stations. The shocks considered general were recorded at five or more stations, but some of them were general only in parts of the Republic. Some of the general shocks—for example, that of the Porto Rico earthquake of October 11, 1918—were of distant origin and were felt in virtually all the Republic. Clearly recognizable aftershocks were not included in the total number of shocks. The location of the stations also affects the graph. Some of them are on alluvial ground, others are on bed rock or on residual soil.

In view of the facts just stated the graph may not seem to be very useful, yet it shows clearly the relative frequency of earthquakes in some parts of the Republic. The large number of shocks recorded in the Northwest Peninsula, at Port-au-Prince, and at Anse-à-Veau indicate that they are the regions of highest seismicity. Moreover, this indication agrees with the results of a study of the disastrous shocks from 1551 to 1908.

The numerous shocks recorded at Môle St.-Nicolas, Gonaïves, Port-de-Paix, and Cap-Haïtien probably originated along the fault zone at the south side of the Bartlett Deep, as did the disastrous shocks of 1842 and 1887. Sea waves are not recorded for any of the shocks from 1908 to 1922, which may therefore have involved small vertical displacement. The largest number of shocks were recorded at Gonaïves and Môle St.-Nicolas, which are closest to the place of supposed origin. Most of the shocks have an intensity of II to IV (Rossi-Forel scale), but a few are as high as V and VI. Some of the shocks—for example, that of February 4, 1918—were relatively strong at Môle St.-Nicolas (IV-V) but were not recorded elsewhere. The earthquake of March 20, 1910, is typical of the minor shocks felt in the northern part of the Republic, particularly in the Northwest Peninsula. It was recorded at Môle St.-Nicolas, Gonaïves, Port-de-Paix, Bassin Bleu (on Les Trois Rivières between Gros-Morne and Port-de-Paix), Cap-Haïtien, Grande-Rivière du Nord, Dondon, and Bahon. A shock that occurred on August 21, 1911, was recorded at Môle St.-Nicolas (IV-V), Gonaïves (V), Gros-Morne (V-VI), Port-de-Paix (V), Pilate (V), Cap-Haïtien, St.-Michel de l'Atalaye, Hinche, St.-Marc (IV), Port-au-Prince (III), Furcy (III), Petit-Goave (II), Anse-à-Veau (III-IV), and Cayes. It is remarkable that this shock was not recorded at Pétionville, for at Furcy, farther from the place of its origin,

it had an intensity of III. Both stations are on bedrock or on residual soil close to bedrock. Scherer remarks that this is not the first time that a general shock was not felt at Pétionville. The highest intensity in the Southern Peninsula was at Anse-à-Veau, and Les Cayes was the only locality on the south coast where the shock was felt.

The earthquake of September 6-7, 1912, apparently had its origin in the interior of the Massif du Nord, as it was strongest at Plaisance (VII), Limbe (VII), Grande-Rivière du Nord (VII), and St.-Michel de l'Atalaye (VII). At Port-au-Prince the intensity was IV-V. The shock was felt at all the stations except Tiburon, Aquin, and Les Cayes.

St.-Marc is strikingly free from frequent shocks, the only shocks recorded there being general shocks originating at some distant locality. The records at St.-Michel de l'Atalaye and Mirebalais show similar features, indicating that the central part of the Republic has fewer earthquakes than the northern and southern parts. The serious earthquake of October 6, 1911, seems to have originated along the southern border of the Massif du Nord, or of its prolongation the Cordillera Central of the Dominican Republic, as Scherer has suggested. The greatest intensity was at San Juan de la Maguana (IX-X) in the Dominican Republic. It was felt at Cerca-la-Source (IX), Hinche (VII-IX), Vallière (VI), Cap-Haïtien (VI-VII), Mirebalais (VI-VII), St.-Marc (VI), Gonaïves (VI), Port-de-Paix (IV-V), Port-au-Prince (VI), and throughout the Republic, the intensity diminishing in all directions from Cerca-la-Source and San Juan de la Maguana. The destruction was not very great, as the region where the intensity was highest is thinly populated and most of the houses are built of wood. The great scarp overlooking Cerca-la-Source from the south may be a fault scarp. (See p. 334 and Pl. XXV, *A*.) If it is a fault it was active at the close of Miocene time, and if it is still active it may account for this earthquake. At Port-au-Prince this shock was the strongest recorded since September 23, 1887, the time of one of the disastrous earthquakes in the northern part of the Republic. Seven aftershocks of intensity II and III were felt at Port-au-Prince.

More earthquakes have been reported at Port-au-Prince that at any other station. Many of them are supposed to be due to movement of the rocks along the fault zone at the south side of he Cul-de-Sac Plain, such as produced the disastrous shocks of 1751 and 1770. If this supposition is correct it is surprising that so few of the shocks were recorded at Gantier, Pétionville, and Thomazeau. Gantier and Pétionville are on bedrock or residual soil, but Thomazeau stands on alluvium. A pronounced vertical movement was felt during many shocks that apparently originated near Port-au-Prince. On July 31, 1914, a shock lasting 40 to 50 seconds at Port-au-Prince had an intensity of V. All of the movement seemed to be vertical. Despite its intensity the shock was purely local and was not felt farther than Pétionville, Furcy, and Léogane. The earth-

quake of July 26, 1917, was the most recent pronounced shock apparently originating near Port-au-Prince, where it had an intensity of VI. The intensity in general decreased away from Port-au-Prince, but it was unusually high at Cap-Haïtien (VI) and Limonade (V-VI). Although the shock was felt throughout the Cul-de-Sac Plain and at Gantier (V), it was not felt at Pétionville and Furcy. Most of the shocks recorded at Pétionville, Gantier, and Thomazeau were felt at Port-au-Prince and generally with greater intensity there.

The most striking feature of the Southern Peninsula is the large number of shocks of low intensity (II-III) recorded at Anse-à-Veau. Probably most of them originated along the south side of the Asile Valley, as suggested for the earthquake of April 8, 1860, but on this supposition more of them should be felt at Aquin and Les Cayes.

The earthquake of August 3, 1910, seems to have been most severe at Jérémie (VII). It was felt over virtually the entire Republic and had an intensity of V at Port-au-Prince and Cap-Haïtien. At many stations a strong vertical movement was noted. An observer on the south coast of Gonave Island felt the shock, but states that the sea was as calm as a lake. The origin of this earthquake is not so clear as for some other shocks, although it is supposed that a fault, active since Miocene time, extends along the north edge of the interior lowland south of Jérémie. (See pp. 226-227 and Fig. 7, p. 137.)

The most recent pronounced shock was on January 15, 1922. The intensity was greatest at Les Cayes (V-VI), where houses even of reinforced concrete were cracked. It was felt all along the south coast as far east as Jacmel (IV), along the north coast of the Southern Peninsula from Jérémie (IV-V) to Port-au-Prince (IV-V), and as far north as Gonaïves (III) and St.-Michel de l'Atalaye (II). In the absence of adequate information it may be suggested that this earthquake had its origin either along the supposed fault at the south edge of the Asile Valley or along the scarp between the Port-Salut Peninsula and the Cayes Plain. This scarp has the appearance of a fault scarp. (See p. 135.)

Conclusions Regarding Frequency of Shocks in Different Parts of the Republic.

An analysis of the disastrous shocks from 1551 to 1908 and of the more detailed records of shocks from 1909 to 1922 indicate that the Northwest Peninsula, the region near Port-au-Prince, and the region near Anse-à-Veau are the areas where earthquakes are most frequent.

The frequency of earthquakes in the Northwest Peninsula agrees with the evidence derived from its geologic features. It is the most mobile region in the Republic, as Quaternary reef caps there have an altitude of 400 to 450 meters above sea level and are more numerous than elsewhere. The elevation of these reef caps is clearly due to the emergence of the

southwestward plunging crest of the Northwest Peninsula anticline. This continued rapid emergence causes strains in the rocks that are relieved by fracturing along the submerged northwest flank of the anticline where it plunges into the remarkable depths of the Bartlett Deep, or by slipping along former fractures at the same place. The strains would be relieved principally by vertical or almost vertical fracturing or slipping. The vertical movements transmitted through the elastic rocks cause the vibrations. If this explanation is correct the serious shocks should cause sea waves. The observer at Môle St.-Nicolas, the station nearest to the supposed place of origin, should record any indications of a sea wave.

Only one earthquake (September 6-7, 1912) seems to have originated in the interior western part of the Massif du Nord. There is a fault of considerable displacement on the south slope of Mont Puilboreau near its crest (see Fig. 18, *C*, p. 311), but it probably was active at the end of Eocene time and there is no other evidence that it is still active. The interior eastern part of the Massif du Nord, which is a great batholith of quartz diorite, is probably the most stable area in the Republic. This supposition could be verified by obtaining records at Vallière. The southern border of the massif is relatively stable, although one shock of high intensity (October 6, 1911), originated near Cerca-la-Source.

Thrust faults along the southwest edge of the Central Plain, active at the end of Miocene time, seem to be no longer active, but this region is thinly populated, and minor shocks originating there might not be recorded.

No shocks seem to have originated near St.-Marc or in the Artibonite Valley. On both sides of St.-Marc there are plunging anticlines bearing Quaternary reef caps resembling in miniature those of the Northwest Peninsula. It might be supposed that the emergence of these reef caps would produce strains; if so, they have not caused rupturing of the rocks during the time since the region was colonized. The thrust faults along the southwest flank of the Chaîne des Mateux near the Arcahaie and the Cul-de-Sac plains (see Fig. 5, p. 128 and Fig. 21, p. 335) are evidently no longer active, as no shocks have originated near l'Arcahaie.

If the interpretation of the numerous shocks at Port-au-Prince given on page 342 is correct the thrust faults along the south edge of the Cul-de-Sac Plain have been active during historic time, and there is no indication that their activity has ceased. Many of the shocks seem to be due to vertical or almost vertical displacement indicating corresponding movements along the high-angle thrust faults. The cause of the strains thus relieved is not known but may be related to the emergence of the Cul-de-Sac Plain, which was submerged early in Quaternary time.

It is hoped that M. Scherer can find a correspondent at l'Asile. If the unusually numerous shocks recorded at Anse-à-Veau are due to displacement along the south side of the Asile Valley the shocks should be

of higher intensity at l'Asile. A correspondent at Baradères could furnish records that would be valuable in fixing the limits of this highly seismic area. The rest of the Southern Peninsula seems to be fairly stable, although one shock (August 3, 1910) seems to have originated near Jérémie, and the most recent widespread shock (January 15, 1922) had its origin near Les Cayes. The central basalt in the Massif de la Selle is limited on at least the north side by faults, which apparently are no longer active.

M. Scherer should enjoin his correspondents at all stations on the coast to collect faithfully any information concerning sea waves, particularly during shocks of high intensity.

There are so many faults in Haiti that any shock originating on the land could plausibly be considered the result of movements along some fault, but it is difficult actually to prove that any fault is still active. The only faults that have been regarded as probable places of origin of earthquakes have been active since Miocene time. Surface indications of recent activity are usually soon obliterated, and even immediately after they are formed a careful search generally is required to reveal them. No surface indications were seen during the reconnaissance. The only way actually to prove, for example, that the numerous shocks at Port-au-Prince are due to movements along the faults at the south edge of the Cul-de-Sac Plain would be to determine the region of highest intensity after a serious shock and then search for signs of a recently active fault.

Precautions Against Damage.

Earthquakes have been very frequent in Haiti, particularly in the Northwest Peninsula, at Port-au-Prince, and at Anse-à-Veau. At times they have been disastrous. Shocks may be expected to continue at frequent intervals and some of them may devastate the most thickly populated parts of the Republic. No one can predict when the shocks will come or at how frequent intervals they will be disastrous. Port-au-Prince was almost or completely destroyed twice within the period of 19 years from 1751 to 1770, but disastrous shocks are usually not so frequent. In such a region disaster is invited unless precautions are taken. The earthquakes can not be warded off, but buildings and other structures can be so located and constructed that they will most successfully stand the shocks. The following precautions are taken from the account of Professors Reid and Taber, who investigated the Porto Rico earthquake of October 11, 1918.[1] Methods of building construction in Porto Rico are very similar to those used in the Republic.

Shocks are more severe on alluvial soils, especially soils that are saturated with ground water, than on bedrock or on residual soils. Most of

[1] Reid, Harry Fielding, and Taber, Stephen, The Porto Rico earthquake of 1918, with descriptions of earlier earthquakes: 66th Congress, 1st Session, House of Representatives Document 269, 74 pp., 6 figs., 1919 (see pp. 69-74); The Porto Rico earthquakes of October-November, 1918: Seismol. Soc. America Bull., vol. 4, pp. 95-127, pls. 7-14, 1919.

the large cities and towns in Haiti stand along the coast and are built wholly or in part on alluvium. The location of many city buildings on alluvium is therefore unavoidable. The possibility of damage is diminished by extending the foundations to bedrock, if possible. Virtually the same result is obtained by building on a thick reinforced concrete plate, which causes the building to move as a whole. Contacts of alluvium with bed rock, escarpments, and river banks are especially dangerous locations.

Buildings and other structures should be either so elastic that they yield without breaking or so strong that the shocks can not seriously injure them. Wooden buildings are one type of elastic structures. They should be well braced and the joints should be strong enough to resist pulling apart. For some time after the earthquake of June 3, 1770, the colonial authorities permitted only wooden buildings to be built in Port-au-Prince. The chief objection to the use of wooden buildings in the tropics is that they rapidly deteriorate through rotting and the attacks of termites and other insects. The common type of houses in the country districts and in the city districts where the poorer classes live are virtually immune from damage. They consist of wooden frames, usually lashed together with fiber thongs, and the walls are made of wicker, which is sometimes covered with plaster or adobe. Steel-frame buildings, such as the market at Port-au-Prince, are also strong, elastic structures.

Buildings constructed of rigid material, such as brick, building stone, and concrete, should be strong enough to resist injury. Many of the dwellings and public buildings show an inferior type of masonry construction, consisting of stones of irregular size and shape embedded in a poor lime mortar. The soft Quaternary coralliferous limestone is frequently used. The lime used in the mortar is often incompletely burned and imperfectly slacked, and the sand contains many impurities. Several such buildings were being built in Port-au-Prince during our stay there. Buildings of this kind would be the first to fall during a shock of high intensity, and their construction should be prohibited.

Brick buildings will resist any but the strongest shocks if a good mortar is used and the bricks are properly crossed. Clean sand should be used for mortar in both brick and masonry work. The only known large deposits of quartz sand relatively free from impurities are on the North Plain. The binding power of lime mortar is improved by adding cement.

First-class concrete made with clean sand and sufficient cement is fairly strong. Concrete strengthened with steel reinforcements is believed to be the strongest material available.

Heavy roofs, parapet walls around roofs, and overhanging cornices should be avoided. Solid partition walls should be firmly tied to the outer walls. Floor and roof joists should pass through the supporting wall, or at least half a meter beyond the inner face of the wall. They should be entirely free to slide in their recesses or should be firmly attached to the walls with iron plates.

SUMMARY OF GEOLOGIC HISTORY.

By Wendell P. Woodring.

Little is known of the Paleozoic and early Mesozoic history of the Republic. The schistose limestones of Tortue Island, which are probably marine, are of Paleozoic or early Mesozoic age, but the distribution of land and sea when they were laid down and later events in early Mesozoic time are not known. The intensely metamorphosed schists found as float on the North Plain and the Léogane Plain are altered igneous and sedimentary rocks at least as old as the schistose limestones. There may be relatively large areas of these ancient rocks in some of the unexplored rugged mountains, such as the Montagnes de la Hotte. They were formerly extensive in the eastern part of the Massif du Nord, as younger rocks contain material derived from them.

The known Mesozoic history begins with a long-continued period of vulcanism in the northern part of the Republic. There were extensive flows of basaltic lavas, followed by flows of andesitic and dacitic lavas. At some places, basaltic flows followed the andesitic lavas. The flows came from non-explosive vents, as very little pyroclastic material accompanies them. These volcanic rocks probably are largely of Jurassic age. The earlier basaltic lavas are very much altered and at places have been converted into greenstones and amphibolites. No trace was found of the Triassic sea that extended westward from the European Mediterranean to Cuba and Mexico, carrying with it a Mediterranean and later a north European fauna.

The early volcanic rocks of the northern part of the Republic were then attacked by weathering and erosion and the material derived from them was deposited along the flood plains of streams that carved wide, gently sloping valleys. Some of the material was laid down in shallow seas that extended over an unknown part of the country. These nonmarine and marine rocks are the argillites and limestones of supposed Lower Cretaceous age. At the same time shallow seas covered a large part of the present Southern Peninsula and the limestones found at many localities were laid down on a basement of unknown rocks.

In Upper Cretaceous time a shallow sea covered at least part of the northern part of the Republic. Its limits are not known, as the rocks of this age that were found probably are mere remnants. A typical Mediterranean fauna, consisting principally of Rudistid mollusks, flourished in this sea. At places the Upper Cretaceous limestone is a Rudistid reef, consisting of masses of valves, some of which are a meter or more in length. This fauna, apparently of late Upper Cretaceous age, has been found in St. Croix, Porto Rico, the Dominican Republic, Cuba, and Jamaica, but it seems to be most extensive in Jamaica.[1]

While this sea covered parts of the northern part of the Republic there were fissure eruptions in the southern part, covering low-lying lands with thick flows of basalt that is remarkably uniform from the Massif de la Selle westward to the end of the Southern Peninsula. Material derived from these flows and some of the flows themselves were deposited in shallow marginal seas.

Mesozoic time apparently was closed by a period of folding, but it is difficult to ascertain, in most places, what elements of the present structure are due to Mesozoic movement and what to later Tertiary movements. Intrusions of batholiths and stocks of quartz diorite accompanied or followed the folding in the northern part of the Republic, altering the old volcanic rocks near the contacts to amphibolites and to chloritic and talcose schists. These masses of quartz diorite are exposed by erosion from the Dominican border westward to the Northwest Peninsula. The largest exposed batholith is in the eastern part of the Massif du Nord, and this region was very rigid during later time.

Early Eocene time was a period of erosion, and if there were then any highlands they were rapidly worn down, exposing in the northern part of the Republic the batholiths and stocks of quartz diorite. During middle Eocene time the sea covered part of the Massif du Nord and the Northwest Peninsula, and in it the Plaisance limestone, which carries a Mediterranean fauna, was deposited. The trough in which this limestone was laid down probably was much larger than the present outcrop of the limestone, but its boundaries are not known.

The extensive transgression of the sea in late Eocene time is one of the outstanding features of the Tertiary geologic history. Its shallow waters covered almost the entire Republic except the northeastern and probably the western parts of the Massif du Nord. The many different kinds of limestone, which cover so large an area, were deposited in this sea. Foraminifera of Mediterranean aspect are the most common fossils in the rocks. At the end of Eocene time the sea withdrew and for a period there was apparently folding, the results of which, however, are almost as obscure as those of the folding at the end of Cretaceous time.

Early Oligocene time, it seems, like early Eocene time, was a period of widespread emergence and erosion. The sea returned again in middle Oligocene time, but its transgression was less extensive than in late Eocene time. A shallow sea covered large areas, particularly in the central part of the Republic, which was very mobile during Tertiary time. The rocks of middle Oligocene age, like the Eocene rocks, are limestones, indicating that the waters were clear. The history of the events between middle and upper Oligocene is rather obscure. During this interval there were flows of

[1] See recent articles by C. T. Trechmann, The Cretaceous and Tertiary question in Jamaica: Geol. Mag., vol. 59, no. 699, pp. 422-431, 3 text figs., 1922; The Barrettia beds of Jamaica: Geol. Mag., vol. 59, pp. 501-514, pls. 18-20, 1 text fig., 1922.

nephelite basalt in the Montagnes du Trou d'Eau. Farther west, near Saut d'Eau, the volcanic activity may have been of Miocene age. The nephelite basalt and other basalts interbedded with Miocene sedimentary rocks on the southwest slope of the Chaîne des Mateux represent the last known period of volcanism. The late Oligocene sea covered a smaller area than the middle Oligocene, the largest areas being in the mobile central part of the Republic. The upper Oligocene rocks are limestones. The most common fossils in both the middle and upper Oligocene limestones are Foraminifera and corals of Mediterranean aspect.

The end of Oligocene time was a period of extensive elevation except possibly in the central part of the Republic. Detrital débris derived from the highlands was carried into the Miocene sea as it advanced. Near old land masses, as in the Central Plain, the Miocene rocks consist almost entirely of detrital material, although clearer waters at intervals permitted the establishment of coral reefs. The early Miocene trangression was the most extensive except that in the late Eocene. The sea covered all of the Northwest Peninsula except the central part, all of the central part of the Republic, and parts of the Southern Peninsula. This was the last extensive transgression and also the last appearance of a Mediterranean fauna. It would be more correct to consider the Mediterranean Tertiary faunas as having a West Indian aspect. Many of the genera of mollusks found in the Miocene Tertiary faunas of the West Indies and the Mediterranean region are now living in the West Indies but are extinct in the Mediterranean Sea. The present Mediterranean fauna is the result of invasions of northern genera in Quaternary time. The sea probably covered the Cul-de-Sac Plain and marginal parts of the Southern Peninsula in middle Miocene time. Nonmarine deposits in the interior of the Southern Peninsula seem to be of the same age.

Toward the end of Miocene time there was a period of folding that determined the tectonic features of a large part of the Republic. Intrusions of quartz diorite and granodiorite in upper Eocene beds may have accompanied or followed this folding in the Montagnes de Terre-Neuve. The mountain ranges in the central part of the Republic coincide with anticlinal arches formed at the end of Miocene time. It is not known whether the arches were elevated as mountains at the same time. Miocene and even older rocks are completely removed from their crests, and in the Chaîne des Mateux there is evidence of peneplanation. All this erosion may have taken place when the present mountains were at a lower altitude. The mountains in the northern part of the Republic and in the Southern Peninsula probably have been highlands since the end of Oligocene time, although they may have shared in the elevation after the Miocene folding. The normal faults bounding the Trois Rivières trough seem to be later than the folding and may be genetically related to the elevation of the mountains that followed the folding.

During middle or late Miocene time the West Indian islands were apparently larger than they are now, and they may have been joined to South or Central America, thus permitting the invasion of a mammalian fauna of South American aspect, principally rodents and ground sloths. These mammals are represented by Quaternary remains found in caves, such as those explored near St.-Michel de l'Atalaye. The folding and faulting begun toward the end of Miocene time probably outlined the island of Haiti as we now know it.

So far as known the sea covered only small areas near Jacmel and Petit-Goave in Pliocene time. The corals and mollusks in the beds in these areas are very similar to living West Indian species. The period of folding begun in Miocene time continued after these beds were deposited.

At the beginning of Quaternary time the sea covered the western part of the Northwest Peninsula, the Cul-de-Sac trough (which divided the island into two parts), and other smaller areas along the present coast. These regions have emerged since then. In the Northwest Peninsula and the mobile central part of the Republic, where the emergence apparently is still continuing, the marine Quaternary rocks, or reef caps, are at a higher altitude on the crests of the anticlines, indicating that folding is still continuing. If observations could be extended over a long period it might be possible to determine the rate of emergence in the Northwest Peninsula, where Quaternary reef caps have an altitude of 400 to 450 meters above sea level.

In the San Juan Valley of the Dominican Republic basaltic lavas of Pliocene or Quaternary age rest on Pliocene gravels. No trace of these lavas was found in the Central Plain.

Folding and mountain-making have been active in the Republic since late Tertiary time and therefore earthquakes are frequent. There is no reason to believe that their frequency will diminish.

Part III. GEOMORPHOLOGY.

By Wendell P. Woodring, John S. Brown, and Wilbur S. Burbank.

The term geomorphology as used in this report signifies a description of the surface features of the earth with regard to their origin. Each of the geographic provinces of the Republic of Haiti comprises an area in which the surface features have a certain uniformity, usually the result of a common geologic history. These provinces are listed on page 31 and their location is shown on Plate XXVII. They are here described in the order in which they are listed on page 31, beginning in the northern part of the Republic. Only the major surface features of each province are described. As it seems unnecessary to repeat a discussion of the major events in the geologic history of each province, the reader should keep constantly in mind the geologic history of Haiti as outlined on pages 350-353. The lithology and the structure of the surface rocks, which are the most potent agencies in determining the shape of the features, are described briefly for each province.

TORTUE ISLAND.

GENERAL RELATIONS.

Tortue Island is 37 kilometers long and has a maximum width of 7 kilometers. It is separated from the mainland by a channel that is 15 kilometers wide at the west end of the island and 9 kilometers wide at its east end but that narrows to 7 kilometers off St.-Louis du Nord. The maximum recorded depth of the channel is 1,267 meters (693 fathoms) off the west end of the island. In the narrowest part of the channel the maximum recorded depth is 777 meters (425 fathoms).

The axis of the island trends N. 78° W., parallel to the trend of the main structural features of the Massif du Nord.

LAND FEATURES.

Upland Forms.

Tortue Island is a plateau modified by erosion and at the margins further modified by the results of recent emergence. The interior is a rolling plateau, the crest of which has a mean altitude of about 300 meters above sea level, but low, rounded knobs rise 325 meters above sea level. The plateau slopes gently seaward, both to the north and to the south. On the crest of the plateau there are no well-defined drainage channels. Near the

coast the slope is steep and is scarred by ravines that have slightly dissected the plateau by headward erosion. All the coastal ravines are short except those at La Vallée, on the south coast, where several extend far back into the plateau, forming a huge, intricately dissected amphitheater bounded by limestone cliffs.

Shore Features.

The most striking shore features are emerged coastal terraces. These terraces are widest and best preserved at the extremities of the island, where the seaward slope is more gentle than on the flanks. Plate XXVIII, *A*, a view of the east end of the island as seen from the south, shows clearly the profile of two emerged terraces. Each of the terraces has a gentle seaward slope and each has an emerged sea cliff at its inner edge. The lower terrace is truncated at the shore line by a similar but steeper cliff. As this part of the island was seen only from a distance no measurements were taken, but at other localities visited the inner edge of the lower terrace stands about 15 meters above sea level. The altitude of the upper terrace is not known, but the vertical interval between its outer edge and the outer edge of the lower terrace is greater than that between the lower terrace and the shore line.

On the south coast the terraces have been obliterated by erosion except in sheltered regions. One kilometer west of Pointe des Oiseaux there is a narrow remnant of the lower terrace 50 to 80 meters wide. At the outer edge there is a perpendicular sea cliff 8 to 10 meters high. The steep slope at the inner edge of the terrace merges into the coastal slope of the plateau and is not clearly discernible as a sea cliff. The abrasion platform is composed of schistose limestone, which is covered with a thin veneer of soft conglomeratic coralliferous limestone.

The west end of the island and the north coast were seen only from a distance. Terrace profiles are visible at the west end, and according to the description of Moreau de St.-Méry[1] terraces are conspicuous features at some localities on the north coast.

Along almost its entire length the north coast is truncated by sea cliffs and is inaccessible. The south coast is not so precipitous. At La Vallée an alluvial apron extends westward along the coast, embracing a narrow mud flat fringed with mangrove thickets. East of La Vallée the coast is bordered by sea cliffs that truncate remnants of the lower terrace.

SUBLITTORAL FEATURES.

A very narrow sublittoral platform encircles the island. Its width on the north coast is not known, but on the south coast its maximum width, as limited by the 20-fathom line, is 2.6 kilometers. The mean depth of water on the platform is about 15 fathoms (27 meters). In Haiti such narrow, shallow platforms are, with certain exceptions, characteristic of

[1] Idem, vol. 1, pp. 739-740.

shore lines of emergence. The width of the emerged coastal terraces is comparable to the width of the sublittoral platform, and it is inferred that these terraces were planed off by wave erosion during periods of time comparable to the time that elapsed during the making of the sublittoral platform. The emerged terraces are of Quaternary age and are probably Pleistocene, as along the south coast they are strongly dissected and at some places entirely obliterated.

NORTH PLAIN.

EXTENT AND GENERAL FEATURES.

The name North Plain has been applied since the early colonial period to the plain that extends along the north coast of the Département du Nord from Acul Bay eastward to the Dominican border. Its length is about 65 kilometers and its width is 5 to 20 kilometers. Its eastward prolongation in the Dominican Republic, which extends from the international boundary and Manzanillo Bay southeastward to Samaná Bay, is called the Cibao Valley. The western part of the Cibao Valley, adjoining the North Plain, is called the Valley of Rio Yaque del Norte. Between Acul Bay and Cap-Haïtien Bay the North Plain is separated from the sea by a short, rugged mountain range called the Morne du Cap. Elsewhere the plain fronts the sea. The southern border of the plain is the steep and very irregular mountain front of the Massif du Nord. From an altitude of 50 to 150 meters above sea level, at the base of the mountains, the plain slopes gently northward to the sea.

LAND FEATURES.

The North Plain comprises four divisions, each of which has distinct surface features: (1) an alluvial plain, which has little or no relief, adjacent to the shore line; (2) a dissected plain composed of gravels of Quaternary age; (3) low hills composed of bed-rock; (4) a rock platform of irregular width at the base of the mountains.

Undissected Alluvial Plain.

The seaward part of the North Plain is an undissected alluvial plain composed principally of deposits of Recent age, built by streams that flow northward in shallow trenches and that probably inundate large areas during floods. This part of the plain is widest along the Dominican border north of Ouanaminthe and narrows westward, terminating in the marshes on the right bank of Rivière Haut du Cap near Cap-Haïtien.

Dissected Plain.

Back of the undissected plain, in the region east of the longitude of Fort-Liberté, lies a dissected plain composed principally of stream gravels of Quaternary, probably Pleistocene, age. This plain is a conspicuous

feature northeast of Acul Samedi and extends eastward to Ouanaminthe. Large areas of the plain consist of grassy or bushy savannas. The ravines and narrow stream valleys are entrenched 5 to 10 meters below the general level of the plain. The transition from this dissected plain to the lower and flatter undissected plain along the coast is gradual.

Low Hills.

Small hills or groups of hills composed principally of many kinds of igneous and metamorphic rocks rise above the plain at several localities. Some of the hills, such as that on which the Gendarmerie post at Ouanaminthe is situated and Morne Beckly, east of Limonade, are so low and rounded that they scarcely break the continuity of the plain. Others, such as Morne Grande-Gille, north of the road from Limonade to Milot, and Morne Pelé, east of the railroad between Grande-Rivière du Nord and Cap-Haïtien, rise more steeply to altitudes of 50 meters or more above the plain. East of the head of Acul Bay low bedrock hills are very numerous.

Rock Platform.

A narrow rock platform, 75 to 150 meters above sea level, extends along the extremely irregular front of the Massif du Nord. This platform is particularly conspicuous in the vicinity of Les Perches and south of Ouanaminthe. The surface of the platform grades imperceptibly into the gravel-covered plain that bounds it on the north, and the platform itself is at many places so thoroughly covered with a thin veneer of alluvium and residual soil that it may easily be overlooked. It is exposed along the road from Cap-Haïtien to Ouanaminthe, about 5 kilometers east of Terrier-Rouge, where the road skirts the base of a spur that projects out into the plain from the mountains. At this place the rock platform has an altitude of perhaps 75 meters above sea level. The rock platform, like the gravel-covered plain that lies in front of it, is dissected by the present streams, but the valleys, being entrenched in bedrock, are generally narrower than the valleys in the plain. The metamorphic volcanic rocks and quartz diorite that floor the platform are exposed in many road cuts and in ravines. Along the foot of the mountains south of Les Perches, where a deep, rounded embayment of the plain extends into the mountains, the rock platform has an altitude of about 100 meters above sea level. Here it is cut entirely in quartz diorite, which is exposed in the ravines and at many localities along the trails. At some localities the floor is covered with soil and alluvial débris that is as much as 5 meters thick. Along the trail from Ouanaminthe to Mont-Organisé the rock platform has an altitude of about 150 meters above sea level. Quartz diorite crops out along the trail and in the ravines.

The rock platform along the front of the Massif du Nord is apparently an abrasion platform cut by wave erosion when the sea stood at a higher

level, and some of the features of the steep, irregular front that faces the platform are believed to be due to the cutting of sea cliffs. In other parts of Haiti rock platforms that are known to be abrasion platforms cut by wave erosion are veneered with coralliferous limestone or beach shingle. No deposits that are obviously marine were seen on the rock platform at the rear of the North Plain, but some of the gravels on it may be of marine origin. As the cliffs along the shore of this supposed abrasion platform were very high, detrital rock material may have been carried into the sea too rapidly to permit the growth of corals on the inner part of the platform, the only part that is now exposed.

The cutting of this platform apparently determined the present outline of the southern border of the North Plain. As the platform is higher near the Dominican border than it is farther west, the emergence that followed the cutting of the platform was progressively less westward. The outer part of the emerged platform was covered with stream gravels that now underlie the dissected plain adjacent to the platform. The trenching of the streams in this plain and in the platform indicate renewed emergence, probably at the end of Pleistocene time. The undissected seaward plain probably is wholly of Recent age. Some of the shore features indicate later submergence.

Shore Features.

From the Dominican border to Cap-Haïtien the shore of the North Plain consists principally of low sandy beaches. The shore line of the western part is indented by Caracol Bay. East of Caracol Bay the shore line is straighter but is broken by Fort-Liberté Bay.

Fort-Liberté Bay is the only bilobate pouch-shaped harbor in the Republic. It was not examined during the reconnaissance, but its features as shown on the coast charts indicate that it is similar to the Cuban pouch-shaped harbors, the origin of which has recently been considered by Vaughan.[1] The outline of Fort-Liberté Bay is probably due to submergence following the emergence that caused the streams to trench the inner part of the plain, but its history can not be given until field studies have been made. The mouth of Rivière Massacre, the largest stream in the region, is not embayed, and the streams that enter the digitations of the bay are very small. These features indicate that the history of this pouch-shaped harbor is more complex than the history of the Cuban harbors.

SUBLITTORAL FEATURES.

At the Dominican border a wedge of deep water extends into the head of Manzanillo Bay between the extensive platform of Monte Cristi bank

[1] Vaughan, T. Wayland, Contributions to the paleontology of the Canal Zone, Panama, and geologically related areas in Central America and the West Indies: U. S. Nat. Mus. Bull. 103, pp. 280-286, 1919.

and the coast of the Republic of Haiti. A very narrow sublittoral platform extends westward along the coast from the Dominican border. Between Fort-Liberté Bay and Caracol Bay the platform widens, as its outer edge maintains a northwesterly direction, diverging somewhat from the shore line opposite the shallow inlet of Caracol Bay. The significance of the narrow platform off Fort Liberté is not known. In other parts of the Republic shore lines of submergence have wider sublittoral platforms or show traces of a submerged terrace scarp.

MASSIF DU NORD.

NAME AND EXTENT.

The name Massif du Nord is here used for the northern mountain system of the Republic. It comprises a complex group of mountains and mountain ranges that extend from the Dominican border westward to the vicinity of Gros-Morne. The Massif du Nord is the northwestward prolongation of the Cordillera Central of the Dominican Republic. In the Republic of Haiti the belt of mountains is narrower, and as it occupies the northern part of the Republic a name similar to that given it in the Dominican Republic would be inappropriate. Many of the peaks and short ranges in the Massif du Nord have separate names, but no names are known for the major ranges.

The eastern half of the massif is bounded on the north by the North Plain and on the south by the Central Plain. The western half is bounded on the north by the sea and on the south by the Montagnes Noires, from which it is imperfectly separated by a gap that is traversed by the road from Gonaïves to St.-Michel de l'Atalaye. The deep trough of the valleys of Les Trois Rivières and Rivière la Quinte separates the massif from similar mountains in the eastern part of the Northwest Peninsula. The total length of the massif is about 120 kilometers, and its width is 25 to 40 kilometers.

GENERAL FEATURES.

The Massif du Nord constitutes one of the largest mountainous regions in the Republic. Some peaks in its western part attain estimated altitudes of 1,200 to 1,500 meters above sea level. In its central and eastern parts the altitudes range from 600 to 1,000 meters above sea level. The valleys are deep, and the crests of the mountains rise 300 to 1,000 meters above the valley floors. The relief is greater in the western and central parts than in the eastern part.

The mountains comprise a mass of peaks, short ridges, and longer ranges, the arrangement of which appears systematic only when considered with regard to the structure and the distribution of the surface rocks. As a whole, the massif is a complex northwestward-trending anticline. Many of the minor surface features have a corresponding northwestward trend.

All the massif east of the valley of Grande Rivière du Nord except a narrow band along the border of the Central Plain is composed of metamorphic volcanic rocks, metamorphic detrital rocks, and quartz diorite. The same rocks continue westward beyond the valley of Grande Rivière du Nord, but in the central part of the massif and along the southern border of the western part they are concealed by younger limestone. The metamorphic detrital rocks consist of rather soft argillites that yield readily to erosion and have had a marked effect on the development of the surface features.

LAND FEATURES.

Eastern Part.

The eastern part of the Massif du Nord embraces the region between the valley of Grande Rivière du Nord and the Dominican border. This region has three different types of mountain features.

The northern part of this region from the Dominican border westward beyond Vallière is a mountainous highland. The general surface of the highland is undulating and has an altitude of 600 to 700 meters above sea level. Sharp-crested ridges that generally trend northwestward rise 200 to 300 meters above the general surface. The valleys are relatively shallow and have an altitude of about 500 meters above sea level. The village of Mont-Organisé is near the northern edge of the highland, at an altitude of 700 meters above sea level. Mont Ténèbres, which is west of Mont-Organisé, is the highest peak along the northern edge of the highland. Its crest rises perhaps 200 meters above the level of the highland at Mont-Organisé and from a distance appears rounded. Along the trail from Mont-Organisé to Ouanaminthe there is a difference in altitude of 400 meters between the outer edge of the mountains and the rock platform at their base. The slope is so steep that one viewing it from the plain can hardly believe that a trail ascends it. The uniform surface features of this mountainous highland are the result of the deep erosion of a batholith of quartz diorite.

The region west and south of the mountainous highland is occupied by a complex group of intricately dissected ridges that have a general northwestward trend. Probably the most striking difference between this region and the mountainous highland is the more intricate dissection and correspondingly greater relief. At any one locality the ridges have approximately equal heights. Their crests and the crests of the spurs are rounded. The ridges are separated by deep V-shaped valleys, and their flanks are deeply furrowed by ravines that have an intricate dendritic pattern. The trail from Cerca-la-Source northward to Lamielle crosses three ridges that stand, respectively, 605, 765, and 775 meters above sea level. From the crest of the third ridge the trail descends abruptly to the depression at Lamielle. This depression has the same intricate drainage pattern and

rounded divides that characterize the flanks of the ridges. The surface rocks in this entire region are metamorphic volcanic and detrital rocks.

The southernmost ridge in this part of the massif adjoining the Central Plain is a distinct feature. It is composed of beds of limestone that dip southwestward, toward the plain. This ridge is continuous from Pignon southeastward to the Dominican border. Pic de Pignon, a very conspicuous landmark in the northern part of the plain, is a conical peak that is isolated from this ridge by the gap of Rivière Gouape. From Rivière Gouape southeastward to the pass traversed by the trail from Thomassique to Cerca-la-Source the ridge has a fairly even crest, which is slightly notched by the high pass where the trail from Hinche to Cerca-Carbajal crosses it at an altitude of 600 meters above sea level. The pass along the trail from Thomassique to Cerca-la-Source is wider and has an altitude of only 470 meters above sea level. Southeastward from this pass toward the Dominican border the crest of the ridge descends steeply. The contrast between the south and north slopes of this ridge is very striking. The south slope is a uniform and relatively gentle dip slope, but the north slope, which apparently is a fault scarp, is precipitous and is scarred by high cliffs. To one looking westward from Cerca-la-Source (see Plate XXV, *A*, p. 334), this scarp is very impressive, as it rises to an altitude of perhaps 500 meters above the valley of Rivière l'Océan. The hot springs at Los Pozos, described on pages 562-564, are at the base of this scarp southeast of Cerca-la-Source, where the slope is not so steep.

Central Part.

The central part of the massif, as arbitrarily delimited, extends from the valley of Grande Rivière du Nord and St.-Raphaël westward to Plaisance and Ennery. The most striking surface features of this region are due to the presence of limestone, which covers a larger area in this region than in any other part of the massif. The mountains in this region are not so high as those to the east and west. The road from Ennery to Plaisance crosses Mont Puilboreau, one of the highest ranges, at an altitude of 950 meters above sea level.

The eastern part of this region, near Grande-Rivière du Nord and Dondon, is occupied by intricately dissected mountains composed of metamorphic igneous and detrital rocks. These mountains are bordered entirely on the southwest and in part on the northeast by ranges composed of tilted beds of limestone. The mountains that consist principally of limestone are characterized by deep canyon-like ravines. Some of the mountain slopes—for example, that at St.-Raphaël and the upper part of the southwest slope of Mont Puilboreau—conform to the dip of the limestone. The opposite slope is generally a steep escarpment or even a sheer cliff. The cliffs on the northeast slope of Mont Puilboreau are several hundred meters high. There is a very prominent cliff just west of Dondon. High cliffs may also scar the slopes of gently tilted beds of limestone.

A high ridge called Bonnet-à-l'Évêque extends northward to the edge of the North Plain west of Milot. It is composed of porphyry and metamorphic detrital rocks capped by limestone. The limestone rises above the contact with the underlying rocks in almost sheer cliffs. Christophe's citadel stands on the crest of this ridge at an altitude of 865 meters above sea level. The crest of the ridge north of the citadel is very jagged. From the west wall of the citadel there is a sheer drop of probably 150 meters.

Caves and sink holes are minor features of the limestone mountains. The development of sink holes has not progressed far enough to dominate the surface features except in a few small areas.

Western Part.

The western part of the massif includes all the mountains north of an east-west line drawn through Christophe's citadel and Plaisance. It contains the highest mountains in the massif. Between Acul Bay and Port-de-Paix the mountains reach the sea, but at the mouth of Rivière de Port-Margot they are bordered by a narrow coastal plain.

Between Limbé and Plaisance and between Port-Margot and Pilate the mountains are intricately dissected. They are composed of metamorphic volcanic rocks and have essentially the same features as the mountains in the central region of the eastern part of the massif. The road from Limbé to Plaisance crosses their crest at an altitude of 520 meters above sea level, and the trail between Port-Margot and Pilate reaches an altitude of 540 meters above sea level. Mont Maleuvre, the highest peak south of Port-Margot, has an estimated altitude of 1,200 meters above sea level. The longitudinal profile of the mountains is serrate, but in transverse profile their crests are rounded. The ridges are separated by deep, narrow valleys and their flanks are intricately furrowed by ravines, all of which contain running water. The deep, wide valley of Les Trois Rivières borders these mountains on the south. South of the valley of Les Trois Rivières rises the steep, scarred slope of a limestone range, the northwestward prolongation of Mont Puilboreau. The south slope of this range is virtually continuous with the Montagnes Noires, as the two mountainous regions are separated only by the narrow gap of Rivière d'Ennery. These limestone mountains in the southern part of the massif end abruptly along the fault scarp on the east side of the valley of Rivière le Quinte. Morne Deux Mamelles is a conspicuous peak along this fault scarp. The isolated mass of Gros Morne, which stands near the western edge of the Massif du Nord, southeast of the town of Gros-Morne, towers to an altitude of perhaps 1,200 meters above sea level. It is apparently composed principally of volcanic rocks.

The range that parallels the coast between Port-Margot and Anse-à-Foleur is composed of limestone that dips steeply seaward. Northwest of Anse-à-Foleur this range is separated from the coast by a rolling lowland

underlain by younger detrital rocks. Several streams—for example, those at Le Borgne and Anse-à-Foleur—reach the sea through deep, narrow gaps in this range. At many localities the seaward or dip slope of the range is barely furrowed by ravines, in marked contrast to the intricately furrowed flanks of the higher interior mountains. A very conspicuous peak in the interior about 12 kilometers southeast of Port-de-Paix has an estimated altitude of 1,200 meters above sea level.

Morne du Cap.

The Morne du Cap is a rough, broken mountain that lies between Acul Bay and Cap-Haïtien Bay. It is an outlier and properly a part of the north flank of the Massif du Nord. Its crest, which trends approximately east and west, has an altitude of 600 to 800 meters above sea level, and one peak reaches an altitude of about 827 meters. Its length from east to west is about 12 kilometers, and its width is 7 or 8 kilometers.

The Morne du Cap is composed of a sheet of limestone overlying older metamorphic detrital and igneous rocks. The northward dip of the limestone accounts for the short, steep southern slope and the longer northern slope of the mountain. The southward-facing escarpment, scarred by cliffs, coincides with the cap of limestone. The height of this escarpment and that of the mountain diminishes from east to west. Below the escarpment are gentler slopes in igneous rocks, deeply trenched by ravines that are separated by rounded divides. This slope gradually merges into the low rounded hills that dot the North Plain southeast of Acul Bay, joining the Morne du Cap to the Massif du Nord. The hill on which Fort Belair stands, near Cap-Haïtien, is a good example of this kind of rounded hill.

Most of the longer northern slope of the Morne du Cap is composed of limestone, although many of the ravines are cut down into the older rocks. The limestone extends down to sea level at many localities. The slope is rugged, and small cliffs are common. There are no permanent streams, but the slope is strongly dissected except in certain areas where sink holes are conspicuous features. A semi-detached ridge, called Morne de la Vigie, which reaches an altitude of about 300 meters above sea level, extends northward from Cap-Haïtien. It consists principally of limestone, in which there are conspicuous sink holes, particularly west of Fort Picolet lighthouse, where the rock is a mere mass of fragments honeycombed by holes and caverns.

Drainage.

The drainage pattern differs in different parts of the Massif du Nord. In the regions where volcanic rocks are exposed at the surface the pattern is dendritic, but in regions where limestone and metamorphic detrital rocks crop out the drainage is generally adjusted to the structure.

In the eastern part of the massif most of the streams originate at an apex near Vallière and radiate outward in almost all directions. Some of the streams—for example, Rivière Ténèbres—in a short distance take southeastward or northwestward courses, parallel to the trend of the mountains. The valley of Rivière l'Océan is in a band of argillites that yield readily to erosion. At present this stream has no flood plain but is entrenched 30 meters below the level of a barely dissected old flood plain at an altitude of 400 meters above sea level, on which stands Cerca-la-Source. In its upper course Grande Rivière du Nord parallels the strike of the rocks, but its lower course is transverse to the prevailing structural trend. The river has a very narrow but continuous flood plain.

In the central part of the massif several streams originate at an apex near Marmelade. Most of them flow northwestward or southwestward, parallel to the mountain ranges. Rivière Canot, Rivière Atalaye, Rivière Bouyaha, and Rivière Gouape break across these ranges to reach the Central Plain. Rivière Atalaye and Rivière Bouyaha cross the outermost range in deep, narrow gorges with sheer limestone walls. Rivière Samaná cascades down the dip slope of the limestone range into the Central Plain.

The largest valley in the massif is that of Les Trois Rivières, which is called Rivière de Plaisance at and above Plaisance. This valley, like that of Rivière l'Océan, owes its origin to relatively soft argillites which when once exposed are easily carved into wide valleys. The irregularities in the surface of the valley at Plaisance are due to the complex folding and the varying hardness of these rocks. Les Trois Rivières leaves the outcrop of these rocks at Pilate and flows westward in a wide gorge diagonally across the prevailing trends to Gros-Morne, where it emerges from the massif and turns abruptly northward.

Shore Features.

The Morne du Cap abruptly interrupts the low coast that characterizes the seaward margin of the North Plain. Cap-Haïtien is on a narrow alluvial shelf that skirts the base of the mountain. From the northern edge of the town northward and westward to Acul Bay the mountain reaches the sea. The promontories are truncated by sea cliffs having a maximum height of 100 meters and an average height of 25 to 30 meters. The stretches of steep and unapproachable coast are broken by small areas of alluvium at the heads of little coves.

West of the Morne du Cap the shore line is deeply indented by Acul Bay, a unilateral pouch-shaped harbor, probably a submerged valley. The Morne du Cap borders the northern half of the eastern shore of the bay, but the height of the sea cliffs on the promontories diminishes southward. The remainder of the shore of the bay is low and swampy and forms the western termination of the North Plain.

From Pointe Limbé northwestward to Le Borgne there is a series of small bays separated by rocky promontories. The heads of the bays are

filled with a narrow fringe of alluvium and the unterraced promontories are truncated by sea cliffs.

From Le Borgne to the promontory on the east side of Anse-à-Foleur the shore is the truncated flank of a limestone mountain range and is relatively straight. Sea cliffs here attain a height of 30 to 50 meters. This kind of inaccessible coast is known as côtes-de-fer. The trail from Cap-Haïtien to Port-de-Paix winds up and down the deep, narrow ravines back from the coast. Anse à Foleur and the similar but smaller bay between Pointe Foleur and Cap Rouge lie between truncated unterraced headlands. The heads of both of these coves are filled with alluvium.

Between Cap Rouge and Port-de-Paix the shore gradually assumes the characteristic features of the shore line of the Northwest Peninsula. The low beach along this part of the coast is interrupted by low promontories, which are formed of Quaternary marine deposits. The low truncated promontories on both sides of the small embayment of Port-de-Paix

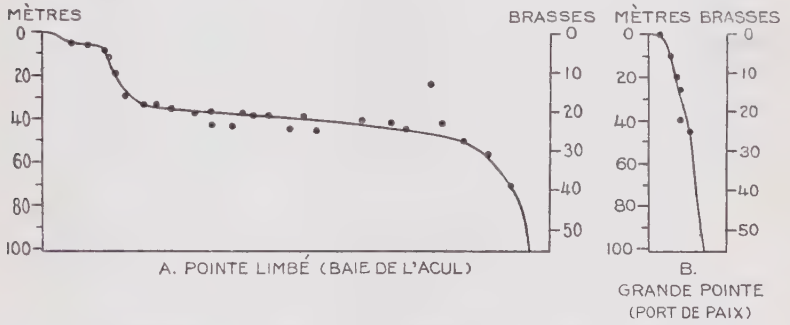


FIGURE 23.—Subaqueous profiles off the north coast.

Horizontal scale 1:70,000. Vertical scale exaggerated 20 times.

harbor are composed of reef rock overlying poorly consolidated gravel and sand. On the west side of the bay the upper surface of the reef rock is about 12 meters above sea level. Between Port-de-Paix and the wide alluvial flat at the mouth of Les Trois Rivières there is a similar low promontory.

SUBLITTORAL FEATURES.

The outer edge of the sublittoral platform off the coast of the Massif du Nord, as limited by the 20-fathom line, has an almost uniform trend of N. 75° W., despite the irregularities of the shore line. Off Acul Bay the platform attains a maximum width of 15 kilometers, but it becomes progressively narrower northwestward. At Port-de-Paix it is indented parallel to the shore line and its maximum width is only 0.5 kilometer. As the depth of the channel in Acul Bay exceeds the depth of water on most of the platform this bay seems to be a submerged valley.

The littoral and sublittoral features of the coast of the North Plain and of the Massif du Nord westward to Le Borgne indicate that this part of the coast of the Republic has been recently submerged. Figure 23, *A*,

shows a subaqueous profile off Pointe Limbé, west of the entrance to Acul Bay, based on chart No. 5251 of the Hydrographic Office, U. S. Navy. The plotted points represent depths recorded along and near the line of profile, which is drawn perpendicular to the contours. The narrow, shallow bank where the depth is less than 5 fathoms (9.1 meters) apparently is a reef, but the lower part of the abrupt slope between 5 fathoms and 18 fathoms (32.9 meters) may be part of a submerged terrace scarp. The wide platform extending seaward from the foot of this scarp slopes from 18 fathoms to 30 fathoms (45.7 meters). This platform seems to be slightly submerged, as in other parts of the Republic wave-cut platforms have a maximum depth of 20 fathoms (36.5 meters). (See Fig. 24, p. 377.) On the east side of the entrance to Acul Bay the submerged platform is obscured by the reefs that are growing on it. Detailed charts are not available for other parts of the coast having shore features characteristic of submergence.

Westward from Cap Rouge the shore line is clearly a shore line of emergence, and the emergence is progressively greater toward the end of the Northwest Peninsula. Figure 23, *B*, a subaqueous profile off Grand Pointe on the east side of Port-de-Paix harbor (Chart No. 5250) is a typical profile of a recently emerged shore line. The significance of these two contrasted types of shore line is considered elsewhere.

NORTHWEST PENINSULA.

EXTENT AND GENERAL FEATURES.

The Northwest Peninsula is a mountainous region resembling in many features the Massif du Nord, from which it is severed by the deep trough here called the Trois Rivières Valley. The name as used here denotes the entire region west of this trough. The length of the peninsula from east to west is about 75 kilometers, and its average width is 35 kilometers.

Several mountain ranges constitute the axis of the peninsula. In the southeastern part of the peninsula the ranges trend about N. 50° W. and attain altitudes slightly more than 1,000 meters above sea level in the communes of Terre-Neuve and Gros-Morne. In the main body of the peninsula the ranges trend approximately east and west and attain altitudes less than 700 meters above sea level. These ranges stand about halfway between the north and the south coast and are bordered on the north and south by lowlands that are only 200 or 300 meters above sea level. The west end of the peninsula is a broad plateau with terraced seaward borders that has a maximum altitude of 450 meters above sea level.

The diversity of surface features is partly due to the diversity of surface rocks. Virtually all the mountain ranges contain a basement of igneous rocks covered by a great thickness of limestone. Soft marls and sandstones extend around the mountains and overlap the rocks that com-

pose them. These detrital rocks are the surface rocks in the lowlands north and south of the central ranges. Coralliferous limestone of Quaternary age veneers the plateau and terraces at the western end of the peninsula.

LAND FEATURES.

Subprovinces.

Although the geographic isolation of the Northwest Peninsula permits its separation as a distinct geographic province, the surface features of different parts of the peninsula are so different that it is divided into six subprovinces—Trois Rivières Valley, Montagnes de Terre-Neuve, Montagnes du Nord-ouest, Bombardopolis Plateau, Arbre Plain, and Jean Rabel Valley.

Trois Rivières Valley.

The conspicuous trough that separates the Northwest Peninsula from the Massif du Nord is here called the Trois Rivières Valley. This trough trends about N. 15° W. along an almost straight line from a locality between Gonaïves and Les Poteaux northward to the mouth of Les Trois Rivières near Port-de-Paix. Les Trois Rivières flows only in the northern part of the trough northward from Gros-Morne, but the trough is prolonged southward from Gros-Morne along the low divide between Les Trois Rivières and Rivière la Quinte and along the valley of Rivière la Quinte to the locality where it enters the Gonaïves Plain. This trough is apparently limited by faults on parts of both the east and the west side.

The valley of Rivière la Quinte has little relief. Along the road from Gonaïves to Gros-Morne the divide between Rivière la Quinte and Les Trois Rivières has an altitude of 270 meters above sea level. The flood plain of Les Trois Rivières northward from Gros-Morne is narrow, and the river swings in great loops against high bluffs. The lowland on both sides of the flood plain is strongly dissected and contains low, rounded hills and higher, narrower strike ridges. A conspicuous strike ridge on the east side of the valley, about 20 kilometers north of Gros-Morne, reaches an altitude of 560 meters above sea level. These hills and ridges are dwarfed by the lofty mountains behind them, in the western part of the Massif du Nord. North of Gros-Morne the mountains west of the valley are not so high.

Montagnes de Terre-Neuve.

The Montagnes de Terre-Neuve extend northwestward from Gonaïves for a distance of about 30 kilometers and comprise several distinct ranges that trend about N. 50° W. The crests of the ranges have an average altitude of 700 meters above sea level, but the altitude of some of the peaks exceeds 1,000 meters. Between the mountain ranges are deep valleys, most of which are V-shaped and some of which resemble canyons. The

slope from the mountains southwestward to the sea and to the southeastern part of the Arbre Plain is very steep, and the slope northeastward to the lowland valley of Rivière la Quinte is almost equally steep.

Most of the mountain crests are rounded and fairly smooth, but the slopes are steep and rough, and are at many places scarred by cliffs, which at some localities, as along the valley of Rivière Colombier west of Terre-Neuve, reach heights of more than 100 meters. The mountains consist of a complex anticline, the axis of which coincides with the axis of the mountain system. The limestone that caps many of the mountains is tilted on the flanks of the folds, thus producing dip slopes and steep escarpments that face toward the crests of the anticlinal folds. Cliffs are common on the escarpments, but are not confined to them, for even on dip slopes erosion in the limestone produces narrow gorges bounded by cliffs. Sink holes are conspicuous features on the more level mountain summits. Some especially large sink holes have a flat floor of alluvium. Such sinks are conspicuous in Section Darane, along the trail from Gonaïves to Terre-Neuve.

Some of the mountains near Terre-Neuve have no cap of limestone and owe their surface features to the erosion of volcanic rocks. The slopes generally are less broken and less precipitous than those in limestone, but the surface is more dissected, and level uplands and smooth slopes are less common. The divides are rounded but narrow. As the volcanic rocks comprise rocks of different hardness, some of the slopes are broken by cliffs, but cliffs are particularly common along contacts between the volcanic rocks and limestone.

There are no large streams in the Montagnes de Terre-Neuve. Rivière Colombier is a small stream that is intermittent, even in its upper course, and disappears completely long before it reaches the Arbre Plain. All the streams have steep gradients and cascades are common. About 3 kilometers southeast of Terre-Neuve a small stream tumbles over a stairlike cascade probably more than 30 meters high. There are other cascades along Rivière Colombier and in Memé Valley along the upper course of Rivière Bassin.

Montagnes du Nord-ouest.

The Montagnes du Nord-ouest comprise three distinct ranges, which extend northwestward from the northwestern end of the Montagnes de Terre-Neuve to the central part of the peninsula and thence westward to the eastern edge of the Bombardopolis Plateau. On some maps these mountains are called the Montagnes de St.-Nicolas, on the assumption that they extend westward between Bombardopolis and Môle St.-Nicolas to the end of the peninsula, but as the mountains nowhere approach Môle St.-Nicolas the name is inappropriate. The westernmost range is situated south of Jean Rabel and may be called the Montagnes de Jean Rabel. No common or appropriate names are known for the other ranges. The

Montagnes de Jean Rabel were visited during the reconnaissance, but the other two ranges were seen only from a distance.

The three ranges collectively are arranged along an arc that is convex northward, but they are more or less *en échelon* and all of them trend north of west. The easternmost range parallels the strike of the older rocks farther south, but the trend of the middle and westernmost ranges swings more to the west, although the strike of the older rocks in the westernmost range is north-northwest.

The easternmost and highest of the three ranges rises abruptly from the northeast border of the Arbre Plain. To the southeast a deep, narrow valley imperfectly separates this range from the Montagnes de Terre-Neuve, and the surface features of the two regions seem to be quite similar. Much of the range appears to consist of limestone and is characterized by steep slopes and high precipices.

The middle range is the lowest of the three. It is in the middle of the peninsula between the Arbre Plain and the Jean Rabel Valley and is almost if not entirely separated from the range to the east by a deep gap extending northeastward from the Arbre Plain. This range appears to be less rugged than either of the other two and lacks the prominent cliffs and escarpments that characterize them. It probably contains less limestone and more igneous rocks.

The westernmost range, or Montagnes de Jean Rabel, rises 850 meters above sea level. Seen from the Arbre Plain, to the southeast, the crest appears to be a great square block with a comparatively flat top and nearly perpendicular white cliffs on the sides, surmounting a dissected pyramidal base of gentler slope. Undoubtedly the range is crowned by a thick cap of limestone, which rests upon a mass of igneous rocks. The lower and less rugged foothills consist in part of the igneous rock that underlies the limestone and partly of the soft marls that overlie the limestone. The interior of the range is deeply dissected, and the underlying igneous rocks are exposed in the valleys. The bottoms of the valleys generally are V-shaped, but the upper slopes in the limestone are at many places scarred by high cliffs.

Bombardopolis Plateau.

GENERAL FEATURES.

The Bombardopolis Plateau, named for the principal and only important town in this region, is a high and relatively flat upland that embraces most of the Northwest Peninsula west of the longitude of Jean Rabel and Baie de Henne. To the east it is bounded by the Jean Rabel Valley, the Montagnes de Jean Rabel, and the Arbre Plain. A long, narrow valley that extends northwestward from Baie de Henne separates the plateau proper from the genetically similar ridge that extends southeastward to Port-à-Piment, bordering the west side of the Arbre Plain.

The width of the plateau proper is 15 or 20 kilometers from east to west, and its length is about 26 kilometers from north to south.

The most striking feature of this region is the remarkable series of well-preserved emerged coastal terraces that extend from the surface of the plateau down to the shore line like gigantic stairs.

Coralliferous limestone of Quaternary age covers almost the entire plateau, and the successively lower terraces are veneered with similar but progressively younger coralliferous limestone. The coralliferous limestone on the plateau clearly veneers an abrasion platform that has been planed by wave erosion from a terrane consisting of folded chalky limestone, cherty limestone, and sandy limestone containing boulders and subangular fragments of volcanic rocks. These older rocks are exposed on the outer edge of the plateau along the trail between Baie de Henne and Bombardopolis. The Chaîne des Desforges, a low mountain range along the outer edge of the plateau southwest of Bombardopolis, probably is composed of these older rocks. Volcanic rocks crop out on the lower slopes of the outer edge of the plateau at Le Plateforme. This region was not seen during the reconnaissance, but has been described by Lütgens,[1] who interpreted this area of volcanic rocks as half of the crater of a volcano that was active during late Tertiary and Quaternary time. The evidence is unconvincing, and it seems more likely that the basaltic volcanic rocks are older than the Eocene limestone.

The surface of the plateau, which rises to an altitude of 400 to 450 meters above sea level, is flat or gently rolling and is imperfectly dissected. The average relief does not exceed 20 or 30 meters. The few valleys generally are narrow and steep-sided. The lack of surface streams in large areas seems to be due to underground drainage in the limestone. Many of the small valleys are of the sink-hole type. Their trend is north-northwestward or northward, apparently conforming to the trend of the underlying Eocene limestone, which, at least along the trail from Baie de Henne to Bombardopolis, strikes in the same direction. Near the eastern margin of the plateau along this trail there is a remarkable series of small parallel valleys that drain northward into the valley extending northwestward from Baie de Henne. Cherty limestone and sandy limestone, probably of Eocene age, are exposed in the bottom of these valleys. The following four strike readings were taken in the bottoms of four valleys, each of which trends parallel to the strike of the older rocks in a distance of 3 kilometers from east to west: North-south, N. 15° W., north-south, N. 30° W. The suggestion seems reasonable that the strike of the older limestone has controlled the direction of the circulation of underground water in the younger limestone, first producing subterranean streams of a corresponding trend, which by caving and enlarging have been opened to the surface. This kind of erosion, but in an earlier

[1] Lütgens, Rudolf, Geographische und geologische Beobachtungen in Nordwest-Haïti: Geog. Gesell. in Hamburg Mitt., Band 32, pp. 72-75, 1919.

stage, is probably exhibited in the interrupted sink-hole valleys farther west, on the main plateau.

The Bombardopolis Plateau embraces two large valleys that indicate features of an inherited structure. One of these is the deep, narrow valley that extends northwestward from Baie de Henne. At its bottom is a narrow alluvial plain. The other is the valley of Rivière du Môle (also called Rivière la Gorge), which extends northward from the interior of the plateau to Môle St.-Nicolas. This valley is very narrow and has precipitous walls that are at some places fully 200 meters high. Along both sides of the valley of Baie de Henne there are well-preserved emerged sea terraces that extend up to the summit of the plateau. The valley of Rivière du Môle has distinct terraces above the 200-meter level. These coastal terraces along the valley walls indicate that the present valleys occupy depressions older than the coralliferous limestone. The valleys are therefore emerged bays, along which drainage lines have been developed.

EMERGED COASTAL TERRACES.

Emerged coastal terraces are the most striking features of the seaward slope of the Bombardopolis Plateau. The terraces along the north coast extend eastward beyond the boundary of the peninsula; those along the south coast end at Port-à-Piment. The following table shows the altitude in meters above sea level at the outer and inner edge and the approximate maximum width in meters of five distinct terraces on the east slope of the ridge between Petit Paradis and Baie de Henne. The altitudes given are based on the reading of an aneroid barometer and are therefore only approximate. Plate XVII, *A* (p. 246) shows the sea cliff between the fourth and fifth terraces.

Altitude and width, in meters, of terraces on east side of ridge between Petit Paradis and Baie de Henne.

No. of terrace.	Altitude at outer edge.	Altitude at inner edge.	Maximum width.
1	5	15	200
2	30	40	100
3	55	60	100
4	70	80	200
5	95	..	500+

On the west side of the same ridge, the side descending toward Baie de Henne, the terraces are narrower and more eroded. The following terraces were recognized and are designated by the number of the terrace in the preceding table with which they seem to agree in altitude.

Altitudes of terraces on west side of ridge between Petit Paradis and Baie de Henne.

No. of terrace.	Mean altitude.
1	29
2 (?)	47
3	55
4	70–75

Along the trail that ascends the margin of the plateau from Baie de Henne to Bombardopolis the lower terraces are dissected and are difficult to distinguish, but there are at least 20 recognizable terraces between the alluvial plain of Baie de Henne, which has an altitude of 10 meters above sea level, and a conspicuous terrace that has a mean altitude of 195 meters above sea level. The approximate mean altitude of the conspicuous terraces above and including the 195-meter terrace are shown in the following table. Most of these readings were obtained on flat-topped ridges between the northward draining valleys described on p. 370.

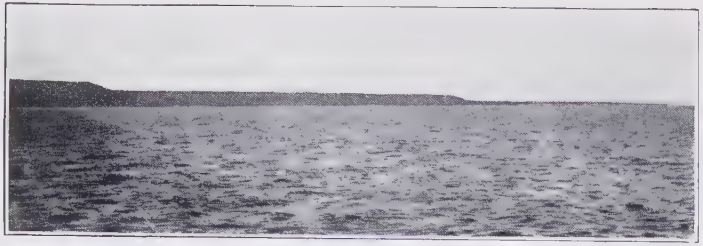
Altitudes and features of terrace between Baie de Henne and Bombardopolis.

Altitude.	Feature.
195	Conspicuous terrace.
225	Terrace.
280	Ridge.
335	Ridge.
360	Ridge.
370	Ridge.
380	Two adjacent parallel ridges.
412–430	Top of plateau.

The following table shows the approximate mean altitude of prominent terraces above and including a 200-meter terrace along the trail between Bombardopolis and Môle St.-Nicolas.

Altitude and width of terraces between Bombardopolis and Môle St.-Nicolas.

Mean altitude in meters.	Width in kilometers.
200	
235	
260–275	1
285	1
325	
345	0.5
360	0.5
400	1



A. EAST END OF TORTUE ISLAND AS SEEN FROM THE CHANNEL TO THE SOUTH.

B. NORTHEAST END OF MÔLE ST.-NICOLAS BAY.

The surface of the isthmus in the center of the view is part of the lowest emerged terrace.

C. CAP ST.-NICOLAS.

EMERGED COASTAL TERRACES.

The preceding table embraces only the upper half of the total vertical interval that is characterized by emerged terraces, as below the 200-meter terrace the trail lies in the bottom of the deep gorge of Rivière du Môle, and the altitude of the lower terraces could not be determined.

The emerged terraces are very prominent along the coast at Môle St.-Nicolas, which has the best harbor in the Republic. The lowest terrace is bordered at the shore line by a sea cliff similar to the emerged sea cliffs at the front and rear of the higher terraces. The peninsula on the north side of the bay is a remarkably flat table-land, corresponding to a terrace that has an altitude of about 45 meters above sea level. In addition to this terrace there are two other conspicuous terraces on the peninsula, one 30 meters above sea level and the other 10 meters above sea level. The bay of Môle St.-Nicolas owes its existence to the emergence of the narrow flat isthmus that ties the peninsula to the mainland. The surface of the isthmus coincides with the lowest terrace and was a narrow channel before its emergence. Heavy storms from the north probably drive a little water across the isthmus even at the present time. The strong trade winds that blow through this gap have developed perfect dunes on a miniature scale near the north coast of the isthmus. Calcareous sand derived from the coralliferous limestone is heaped up in low dune ridges on the surface above the sea cliff.

Plate XXVIII, *B*, a view looking toward the head of the bay from the beach in front of the town, shows the low, narrow isthmus and the terraces on both sides. Plate XXVIII, *C*, a view looking southwestward toward Cap St.-Nicolas from the mouth of Rivière du Môle, shows some of the terraces on Cap St.-Nicolas and on the west side of the valley of Rivière du Môle.

The coast between Môle St.-Nicolas and Baie de Henne was not seen during the reconnaissance, but the emerged terraces are probably as striking at many localities as they are at those two towns. Near La Plateforme the material that forms the terraces has apparently been stripped from the plateau slope, revealing the volcanic rocks and the overlying impure limestone, in which the highest abrasion platform was cut, although La Plateform itself is a table-land capped by coralliferous limestone and apparently forms part of one of the lower terraces.

Southeastward from Baie de Henne to Port-à-Piment the emerged terraces become progressively less numerous and less conspicuous. Between Baie de Henne and Pointe du Petit-Paradis the lowest terrace at many localities is merely an emerged beach less than 5 meters above sea level and generally covered with sand, although the underlying coralliferous limestone is usually exposed in a low cliff at the shore line. At Petit-Paradis a tidal inlet nearly 10 meters deep, entrenched in the youngest coralliferous limestone, is said to connect the sea with an extensive inland lagoon. An emerged beach that has a width of 50 to 150 meters and an altitude of 5 to 8 meters above sea level extends along the coast between Petit-Paradis and Anse Rouge.

The emerged terraces completely disappear at Port-à-Piment, at the end of the terraced ridge separating the northwestern part of the Arbre Plain from the sea. This ridge gradually tapers and its height decreases southeastward from Petit-Paradis.

Along the north coast the emerged terraces extend to and beyond Port-de-Paix. Between Môle St.-Nicolas and Jean Rabel at least six well-preserved terraces rise at increasing intervals to an altitude of perhaps more than 300 meters above sea level. The mean altitude of the lowest terrace is about 10 meters above sea level, of the second 35 to 40, of the third 60. The higher main terraces are separated by greater intervals, but there are many obscure intermediate terraces separated by intervals of no greater magnitude than those between the lower terraces.

The description given shows that emerged coastal terraces become progressively more numerous and reach a progressively greater altitude westward along both the north and south coasts of the Northwest Peninsula. In the Bombardopolis Plateau they reach an altitude of 400 to 450 meters above sea level. The total number of terraces is not known and probably would not be represented in any single profile drawn from the shore line to the top of the plateau because some of the terraces are very narrow or have in places been completely obliterated by the recession of the sea cliff during the cutting of the next younger terrace or by subsequent erosion. It is difficult to recognize the narrow terraces at higher levels, as they are more degraded than at lower levels. In an ascent of the plateau from Baie de Henne to Bombardopolis about 28 distinct terraces were seen.

There is no evidence to indicate that any of the terraces are older than Quaternary. The limestone on the highest terrace contains the same living species of corals as the limestone on the lowest terrace. The terraces are not so conspicuously trenched by the channels of present streams as in other parts of the Republic because the climate is semiarid and underground drainage has been developed.

The emerged coastal terraces of the Northwest Peninsula reach a greater altitude than emerged terraces of the same age in any other part of the Republic. Directly across the Windward Passage at Cabo Maisé, in Cuba, emerged coastal terraces reach an estimated maximum altitude of 185 meters above sea level, greater than in any other part of that island. The two regions are evidently genetically related. The Cuban terraces have been described by Agassiz,[1] by Hill,[2] by Hayes, Vaughan, and Spencer,[3] and by Vaughan and Spencer.[4]

[1] Agassiz, Alexander, A reconnaissance of the Bahamas and of the elevated reefs of Cuba in the steam yacht *Wild Duck*, January to April, 1893: Harvard Coll. Mus. Comp. Zool. Bull., vol. 26, pp. 110-116, 1894.

[2] Hill, R. T., Notes on the geology of the island of Cuba: Harvard Coll. Mus. Comp. Zool. Bull., vol. 16, pp. 267-269, 1895.

[3] Hayes, C. W., Vaughan, T. W. and Spencer, A. C., Report on a geological reconnaissance of Cuba, made under the direction of General Leonard Wood, Military Governor: Civil Rept. Brigadier-General Leonard Wood, Military Governor of Cuba, 1901, vol. 1, pp. 19-20, 1901.

[4] Vaughan, T. Wayland, and Spencer, A. C., The geography of Cuba: Am. Geog. Soc. Bull., vol. 34, pp. 112-113, 1902.

Emerged coastal terraces of the same age and at so great an altitude are not known in any of the other West Indian Islands except Barbados, where they reach an altitude of about 320 meters above sea level.[1]

Emerged coastal terraces of the same age as these remarkable West Indian terraces and at a comparable altitude are not known anywhere along the coast of the United States except along southern California, where, on the island of San Clemente, according to Lawson,[2] there are 17 distinct terraces, the highest of which is 402 meters above sea level. On this island two higher terraces, which are more dissected than the others, have altitudes of 419 meters and 457 meters respectively.

Arbre Plain.

The Arbre Plain is a lowland that lies west of the Montagnes de Terre-Neuve and south of the Montagnes du Nord-ouest. It extends from northwest to southeast and is about 25 kilometers long and almost 10 kilometers wide. Its name is derived from the small settlement, l'Arbre, in the interior of the plain. The name Port-à-Piment Plain is sometimes applied to this plain, but it is unsuitable, as Port-à-Piment is at the margin of the plain and there is another Port-à-Piment on the south coast of the Southern Peninsula. Southeast of Port-à-Piment the plain reaches the sea, but to the northeast it is separated from the sea by a narrow, southeastward-tapering terraced ridge, part of the Bombardopolis Plateau.

Near l'Arbre and on the coast at Port-à-Piment the plain is flat over large areas, but at some places, particularly near the Sources Chaudes, it is dotted with small hills, which have a maximum height of 30 meters. At the border of the mountains, on the north side of the plain, broad alluvial fans spread out and merge into the lowland. The maximum altitude of the plain, including the alluvial fans, is probably not more than 250 meters above sea level. The plain owes its origin to the underlying clay and marl of Miocene age, which readily yield to planation but which are almost wholly concealed by a cover of alluvium.

This plain is very arid, probably the most arid part of the Republic, and its most striking surface features are those that characterize arid regions. The mountains on the north rise abruptly above alluvial fans composed of coarse detrital material. Most of the streams that issue from the mountains disappear in a short distance. In times of flood their waters spread out over wide areas of mud-cracked playa or collect in shallow saline lakes that have no outlet. Several of these lakes lie along the southwestern edge of the plain, near the foot of the ridge that separates

[1] See accounts by Harrison, J. B., and Jukes-Brown, A. J., The geology of Barbados, being an explanation of the geological map of Barbados prepared by the same authors, pp. 27-34, 1890; Jukes-Brown, A. J., and Harrison, J. B., The geology of Barbados; Part I, The coral rocks of Barbados and other West Indian islands: Geol. Soc. London Quart. Jour., vol. 47, pp. 197-243, 9 figs., 1891. (See especially pp. 209-210.)

[2] Lawson, A. C., California Univ. Dept. Geol. Bull., vol. 1, pp. 128-135, 1893.

the plain from the sea. The dissection of the plain is also typical of erosion in arid regions. Wide, dry arroyos and deep gullies with perpendicular unrounded walls are common at some places, particularly in the northwestern part of the plain.

Jean Rabel Valley.

The Jean Rabel Valley is a lowland on the north side of the Montagnes du Nord-ouest, extending from the vicinity of Jean Rabel eastward to the Trois Rivières Valley. Like part of the Arbre Plain, it is separated from the sea by a seaward-sloping ridge composed of limestone of Quaternary age, which is the eastward prolongation of the outer margin of the Bombardopolis Plateau. The seaward slope of this ridge is terraced, but the inner slope is a steep escarpment. Near Jean Rabel the altitude of the ridge is 250 meters above sea level. The same ridge was seen from a distance west of the mouth of Les Trois Rivières, and it probably extends along the entire north border of the lowland but is interrupted by the valleys of a few streams that pierce it and thus reach the sea.

The surface rocks in the Jean Rabel Valley are soft marl, clay, and sandstone, like those in the Arbre Plain. The heavier rainfall in the Jean Rabel Valley accounts for the marked difference in the surface features. Near Jean Rabel, which is the only locality where the lowland was examined, there are two kinds of major surface features—extensive flat alluvial flood plains along the streams and rolling hills that are 100 to 200 meters higher than the alluvial plains. Surface features of this type, consisting of plains and rolling lowlands, probably extend eastward to the Trois Rivières Valley.

As the coastal ridge and the rolling lowland at the rear of the Jean Rabel Valley have virtually accordant summits, the suggestion seems warranted that a plateau formerly extended over the coastal ridge and the entire lowland. The plateau platform, which was the eastward prolongation of the Bombardopolis Plateau, was cut by marine erosion. Subaerial erosion stripped the thin cover of coralliferous limestone from the inner edge of the plateau, revealing the readily eroded Miocene rocks. The resultant enlarged lowland is the Jean Rabel Valley.

Shore Features.

The shore features of the Northwest Peninsula from the mouth of Les Trois Rivières westward to Môle St.-Nicolas and thence southward and eastward to Port-à-Piment are described on pages 371-374.

The Arbre Plain extends down to the sea between Port-à-Piment and Pointe Cordion, and the shore is bordered by mangrove swamps that separate extensive saline mud flats from the sea. At Pointe Coridon sea cliffs truncate an unterraced promontory that is part of a ridge extending

to the coast from the Montagnes de Terre-Neuve. Between Pointe Coridon and Pointe la Pierre the shore consists of a gradually narrowing strip of detritus derived from the steep mountain slopes, fringed by sandy beaches.

SUBLITTORAL FEATURES.

The relation between the width of the shallow offshore platform and the presence or absence of emerged coastal terrace is remarkably uniform along the coast of the Northwest Peninsula. From the mouth of Les Trois Rivières westward around the end of the peninsula and southeastward to Port-à-Piment, the platform, as limited by the 20-fathom line, is very narrow, and its outline closely coincides with the outline of the shore line. This platform, on which reef corals are growing, resembles the numerous emerged terraces. Southeast of Port-à-Piment, where the emerged terraces end, the outer edge of the platform diverges from the shore line, and off Pointe la Pierre the platform attains a maximum width of 10.9 kilo-

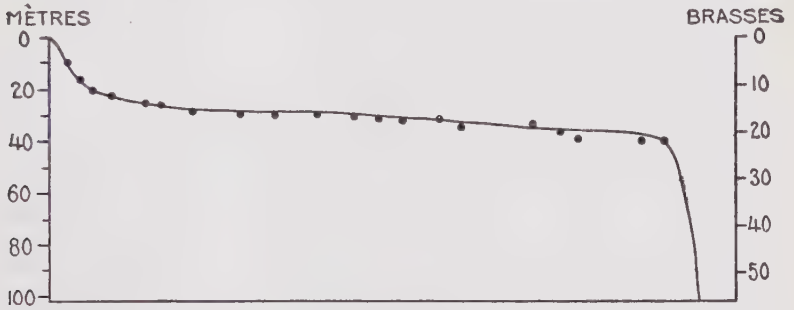


FIGURE 24.—Subaqueous profile off Pointe La Pierre near Gonaïves.
Horizontal scale 1 : 60,000. Vertical scale exaggerated 20 times.

meters. (See Fig. 24.) The conclusion seems warranted that the greater width of the platform is due to the longer interval of time during which it has been subjected to wave erosion. Figure 24 shows that along this part of the coast the maximum depth of effective wave erosion is 20 fathoms (36.5 meters).

The deep indentations in the offshore platform at Môle St.-Nicolas and Baie de Henne indicate that the valleys that extend into the interior of the plateau at these two localities are structural depressions, probably synclines.

CENTRAL PLAIN.

NAME AND EXTENT.

The name Plaine de Goave, or Guaba, was applied by Moreau de St. Méry and other geographers to the extensive plain between the Massif du Nord and the Montagnes Noires. As that name no longer has any local significance, the name Central Plain, first used by Jones,[1] is here used.

[1] Jones, W. F., A geological reconnaissance in Haiti: Jour. Geology, vol. 26, p. 730, 1918.

The Central Plain is the largest interior plain in the Republic. It extends from the Dominican border northwestward to St.-Michel de l'Atalaye like a wedge between the Massif du Nord and the Montagnes Noires. The prolongation of the plain in the Dominican Republic is called the San Juan Valley. From St.-Michel de l'Atalaye to the Dominican border the length of the plain is about 75 kilometers. The northwestern part is 22 kilometers wide, but in the central part the bordering ranges approach each other and the width of the plain is only 16 kilometers. Southeast of this narrow part the width of the plain increases abruptly to 40 kilometers. Toward the Dominican frontier the mountains bordering the plain converge slightly, and along the frontier between Belladère and Bánica the width of the plain is about 30 kilometers.

SURFACE FEATURES.

Northwestern Part.

The northwestern part of the plain is a flat grassy savanna, which slopes southeastward to a point about 10 kilometers northwest of Maïssade. The altitude above sea level at St.-Michel de l'Atalaye is about 425 meters and that at St.-Raphaël about 350 meters. Long reentrants of the savanna extend up main streams at St.-Michel de l'Atalaye, St.-Raphaël, and Pignon. The floor of the savanna consists of flood-plain gravel and silt deposited during a period when the streams were sluggish and meandered over the plain. The extensions of the savannas up the large valleys indicate that the main streams at that time occupied positions approximately the same as at present. These streams have recently entrenched themselves in the flood-plain deposits, probably because their gradient was increased by a change in the course of Rivière Artibonite below Las Cahobas (see p. 382). Rivière Bouyaha at the place where it is crossed by the trail from Maïssade to Pignon is entrenched 25 meters below the level of the plain, and Rivière Gouape, a tributary, is entrenched 15 meters. The smaller streams have scarcely begun to dissect the savanna.

The flood-plain deposits conceal the folded Miocene rocks, which control the surface features in the southeastern part of the plain. West of Pignon and south of St.-Raphaël some low ridges rise to a maximum height of 30 meters above the savanna. These ridges are probably composed of limestone similar to that in the mountains bordering the plain.

North of Maïssade an intricately dissected pine-covered ridge extends from the southeast into the savanna. Along the trail from Maïssade to Pignon the ridge is about 6 kilometers wide and its crest stands about 430 meters above sea level. It narrows toward the northwest and finally disappears beneath the flood-plain deposits of the savanna. The ridge is composed of conglomerate and sandstone.

West and southwest of Maïssade the plain is much more dissected, but flat-topped buttes with accordant summits at an altitude of about 345 meters above sea level indicate that the savanna formerly extended farther southward.

A much greater variety of surface features characterizes the region southwest of Maïssade, where folded Miocene rocks are exposed. An escarpment composed of the calcareous sediments in the upper part of the Madame Joie formation parallels the mountain front, facing outward from the plain. In the vicinity of Rivière Blanche the conglomerates in the Thomonde formation form a second escarpment facing in the same direction, farther from the mountains. This ridge ends abruptly along a fault on the southeast.

An elliptical depression eroded in the finer sediments of the lower part of the Thomonde formation occupies the crest of the Fond Bleu Dome.[1] Encircling it is an inward-facing escarpment formed by the overlying conglomerate. Southwest of the dome these conglomerates form a synclinal ridge with an outward-facing escarpment on the flank near the mountains similar to that in the vicinity of Rivière Blanche. A wide depression formed in the lower Thomonde beds intervenes between this escarpment and the mountain.

Southeastern Part.

Between Hinche and Las Cahobas the western margin of the plain is more rugged. Northeast of Thomonde a spur from the mountains projects southeastward into the plain along the axis of the Thomonde anticline. Several crescentic troughs and escarpments parallel the mountain spur. The largest trough, in which the town of Thomonde stands, coincides with the outcrop of the fine-grained sediments of the Thomonde formation. Near Thomonde the floor of the trough is a savanna deeply entrenched by Rivière Thomonde and its tributaries. The prominent escarpment, or "rim rock," which overlooks this trough is composed of conglomerates and sandstones in the lower part of the Las Cahobas formation. The outlet of Rivière Thomonde is the only gap in this escarpment. Successive dip slopes extend out into the plain from the crest of the escarpment.

The same surface features are duplicated on a reduced scale along the Chamouscadille anticline, south of the Thomonde anticline. Features that are similar but even more reduced appear along the Ayaye anticline south of the Chamouscadille anticline.

Along the foot of the mountains at the southern margin of the plain is a trough coinciding with the outcrop of the Thomonde formation. The town of Las Cahobas stands near the northern edge of this trough on a gravel-covered terrace at an altitude of about 215 meters above sea level.

[1] The Fond Bleu Dome and other structural features are described on pages 488-492.

A high escarpment consisting of conglomerate and limestone at the base of the Las Cahobas formation overlooks this trough. The ruins of old Fort Anglais, north of Las Cahobas, are on the highest part of the escarpment, where the crest is 145 meters above the town. Rivière de Las Cahobas flows northward through a wide alluvium-filled gap in the escarpment. This gap is shown in Plate XIV, *B*, page 168, a view westward from a place about a kilometer northeast of Las Cahobas. The main trail leading northeastward from Las Cahobas toward Thomonde and Belladère follows a narrower and higher gap. Dip slopes extend from the escarpment toward the interior of the plain.

The trough and the accompanying escarpment facing it extend eastward along the southern margin of the plain to the vicinity of Belladère, where they bulge northwestward along the axis of the Belladère anticline, forming a spur much like that at Thomonde. Belladère stands in the trough along the axis of this spur at an altitude of about 360 meters above sea level.

In the interior of the plain the most conspicuous surface features are remnants of a high-level plain and several terraces at lower altitudes. Between Hinche and Thomonde the high-level plain remnants consist of flood-plain deposits and lie at an altitude of about 300 meters above sea level. It is inferred that this plain is the southeastward continuation of the savanna that forms the northwestern extremity of the plain, remnants of which can be traced between Maïssade and Hinche, because if the surface of the isolated remnants were restored it would agree with the slope of the savanna. Entrenching of the streams is shown by terraces, four of which were seen between Hinche and Thomonde at altitudes of about 290, 265, 255, and 240 meters above sea level. The streams are entrenched 10 or 15 meters below the lowest terrace. The older terraces extend across the interstream areas or encircle small isolated patches of the high-level plain. Plate XXIX, *B*, shows three terraces as they appear looking southeastward from a place about 3 kilometers south of Hinche.

Discontinuous terraces extend across the interior of the plain along the trail from Thomonde to Thomassique. Rivière Guayamouc is entrenched 35 meters below a terrace that stands about 235 meters above sea level. Northeast of the river there are higher terraces, at altitudes of about 260 and 300 meters, but the highest terrace may correspond to the high-level plain.

It is inferred that Savane Chamouscadille, which is about 8 kilometers southeast of Thomonde on the trail to Las Cahobas, is an isolated part of the high-level plain. It is covered with flood-plain deposits at an altitude of about 285 meters above sea level. South of this savanna the trail passes near the boundary between the interior of the plain, where terraces are the most prominent surface features, and the western margin of the plain, where tilted ridges composed of Miocene rocks are the most conspicuous features. North of the crossing of Rivière Artibonite there

A. ACCORDANT CRESTS OF STRIKE RIDGES FORMED BY CONGLOMERATES OF THE LAS CAHOBAS FORMATION ON THE SOUTH SIDE OF THE CENTRAL PLAIN.

On the divides many of the ridges have a cap of stream gravels.

B. STREAM TERRACES IN THE CENTRAL PLAIN, AS SEEN LOOKING SOUTHEASTWARD ALONG THE TRAIL FROM HINCHE TO THOMONDE.

are terraces at altitudes of about 265, 235, and 190 meters above sea level. The surface of the alluvium in the present stream valley is 170 meters above sea level. On the south side of the river, as on the north side, the 190 meter terrace adjoins the alluvium; the widest terrace is 210 meters above sea level, and the highest is 225 meters.

Along the trail from Las Cahobas to Belladère the terrace gravels have been stripped off by erosion, except in isolated patches, and the underlying tilted Miocene rocks are exposed. The more resistant beds form low outward-facing escarpments. The accordant height of the summits of these escarpments (see Plate XXIX, *A*) indicates the southward continuation of the high-level plain. On this trail small terrace remnants were seen at altitudes of about 290, 320, and 350 meters above sea level.

The northeast edge of the plain is not so rugged as the west and south edges because the structure is more simple and the lithology of the Miocene rocks is more uniform. The most conspicuous surface features are dip slopes and outward-facing escarpments. Toward the foot of the mountains the dip slopes become steeper and the accompanying escarpments higher. Plate XXXVII, *A*, page 492, shows the dip slopes and escarpments near Thomassique. Toward the interior of the plain the dip slopes disappear beneath the cover of terrace deposits.

Drainage.

The Central Plain lies wholly within the drainage basin of Rivière Artibonite, which enters the plain at the Dominican border near Bánica and flows southwestward. Streams emerging from the mountains around the edge of the plain converge to form the southeastward-flowing Rivière Guayamouc, which joins the Artibonite as its largest tributary, in the south-central part of the plain.

In the northern two-thirds of the plain the drainage system is controlled by the structure, but in the southern third most of it is unrelated to the structure. Instead of continuing southeastward along the plunging trough of the syncline and thus finding access to the sea along the present course of Rio Yaque del Sur, the combined Guayamouc and Artibonite turn southwestward and cut through the high mountain wall of the Montagnes Noires northwest of Las Cahobas. In the absence of adequate maps it is impossible to trace precisely the history of this anomalous drainage. All the evidence available indicates that the plain drained into the San Juan Valley during the time when the high-level flood-plain deposits were laid down. The accordant erosion remnants of a high-level plain that slopes gently southeastward support this interpretation. At that time lateral streams in the southern part of the plain flowed in toward a main central stream, forming a drainage system like that now seen in the northern part of the plain. The flood-plain deposits are apparently of Pliocene age, and this drainage system probably persisted during early Quaternary time.

The entire drainage of the plain, apparently, was first diverted into the present course of Rivière Las Cahobas across the escarpment along the south margin of the plain and through the conspicuous gap in the Montagnes Noires southwest of Las Cahobas, as has been suggested by Tippenhauer,[1] and outlined by Jones.[2] The gap in the escarpment northwest of Las Cahobas seems much wider than it would be if cut by the stream that now occupies it. The gap in the Montagnes Noires southwest of Las Cahobas is all out of proportion to the present small streams that flow northeastward and southwestward from the divide in the gap, which has an altitude of about 245 meters above sea level. The cause of the diversion is not known. The high-level gravels at Las Cahobas and in the valley of Rivière Fer-à-Cheval south of the Montagnes Noires are, according to available information, about 30 meters lower than the gap. If the former surface of the plain were as high as the gap these gravels were deposited during a later stage of the drainage. Additional evidence concerning the outlet of the Central Plain drainage through the Las Cahobas gap, based on the features of the valley of Rivière Fer-à-Cheval, is considered on page 388.

The present gorge of the Artibonite is cut wholly in limestone and its course was probably determined by a former lateral stream in the north slope of the mountains that had an extensive underground drainage. After the gap across the Montagnes Noires at Las Cahobas was deepened down to the basement of volcanic rocks now exposed the deepening proceeded less rapidly, whereas the development of the underground drainage of the lateral streams was accelerated. The final diversion may have been due to the capture of this headward underground drainage by a southwestward-flowing tributary of the Artibonite on the south slope of the mountains. At the time of the diversion the surface of the plain probably coincided with one of the higher terraces along Rivière Artibonite above the mouth of Rivière de Las Cahobas. Between the present gorge and the mouth of Rivière de Las Cahobas the valley of the Artibonite is very narrow, presenting a contrast to the wide terraced valley above.

MONTAGNES NOIRES.

Name and Extent.

The name Montagnes Noires is here used for the mountains between the Central Plain and the Artibonite Valley and their prolongation eastward to the Dominican border. The entire mountain complex is named from the Montagnes Noires, the mountains immediately northwest of the gorge of Rivière Artibonite. The higher mountains farther northwest are generally called the Chaîne des Cahos. The range between the Central Plain and the valley of Rivière Fer-à-Cheval is unnamed.

[1] Tippenhauer, L. Gentil, Neuer Beitrag zur Topographie, Bevölkerungskunde, und Geologie Haïtis: Petermanns Mitt., Band 55, p. 53, 1909.

[2] Jones, William F., A geological reconnaissance in Haiti: Jour. Geology, vol. 26, pp. 748-749, 1918.

Toward the northwest the Montagnes Noires merge into the Massif du Nord, and toward the southeast they are continuous with the northern part of the Sierra de Neiba of the Dominican Republic. The northwestern boundary of the Montagnes Noires is drawn somewhat arbitrarily along the valley of Rivière d'Ennery and southeastward along the pass traversed by the road from Ennery to St.-Michel de l'Atalaye.

Between the valley of Rivière d'Ennery and the Dominican border the length of the Montagnes Noires is about 120 kilometers and their average width is 15 kilometers, but toward the southeast their width is reduced to 6 kilometers or even less.

GENERAL FEATURES.

The northwestern part of the Montagnes Noires comprises several mountain ranges, but the southeastern part is a single range. The trend of the ranges parallels the structural trend. The crest of the southeastern part of the range coincides with the crest of a simple anticline that trends about N. 70° W. This trend extends from the Dominican border westward to the conspicuous gap followed by the road from Mirebalais to Las Cahobas. Immediately northwest of this gap there is a single anticlinal range, but the trend changes to N. 50° W. Farther northwest the Montagnes Noires comprise several ranges, the crest of which generally coincides with the crest of a complex anticline. The conspicuous change in trend coincides with the change in trend of the upper part of the Artibonite Valley and in the mountain system included in the Montagnes du Trou d'Eau and the Chaîne des Mateux. A separate name might be justified for the range southeast of the gorge of Rivière Artibonite, as it strikes into the Artibonite Valley and is separated from the main part of the mountains by a syncline.

Limestones are the surface rocks over large areas in the Montagnes Noires. Older rocks are exposed in the deep valleys and possibly on the crests of the interior ranges.

SURFACE FEATURES.

Northwestern Part.

The northwestern part of the Montagnes Noires was crossed during the reconnaissance only along the trail between St.-Michel de l'Atalaye and Dessalines. Along this trail the mountains include several rugged ranges. The crest of the mountains is crossed at an altitude of 510 meters above sea level, but on both sides of the trail peaks rise to an estimated altitude of 1,200 meters above sea level. Morne Chapelet, a conspicuous peak near Ennery, has an estimated altitude of 1,400 meters above sea level. These mountains are very rugged. Stairlike cliffs rise for hundreds of meters on some of the slopes. Southwest of St.-Michel de l'Atalaye a low range composed of limestone faces the Central Plain. West of this

range Morne Salée rises to an estimated altitude of 800 meters above sea level. In this region the ridges are composed of limestone and are very rugged. The valleys have been cut down to the underlying volcanic rocks, and some of them have been enlarged into rolling interior lowlands. (See Pl. VI, *A*, p. 64.) Near Paul alluvial savannas are common in these lowlands, which have an altitude of about 400 meters above sea level, slightly higher than that of the Central Plain, into which they drain. Some of the valleys near Dessalines are like those near Paul, but they are narrower and have been cut down to an altitude of 100 meters above sea level. The western boundary of this part of the Montagnes Noires is a straight scarp that extends for many kilometers from the eastern side of the valley of Rivière la Quinte southeastward toward Dessalines and rises abruptly 300 to 600 meters above the Gonaïves Plain. (See Pl. XXV, *B*, p. 334.) This abrupt scarp apparently is a fault scarp, along which the western range of the mountains is tilted in a monoclinal block sloping northwestward. This type of structure, which has determined the surface features, extends farther west, as Morne Grammont, an isolated outlier of the Montagnes Noires rising above the Gonaïves Plain southeast of Gonaïves, apparently is a similar monoclinal block. Other hills near the boundary of the Montagnes Noires southeast of Morne Grammont are almost completely buried in alluvium.

Southeastern Part.

The top of the range southeast of the Las Cahobas gap is a rolling plateau, about 4 kilometers wide, in which large areas are covered with residual red clay. The central part of the range consists of limestone, and the slopes from the plateau are much steeper but less intricately dissected than those in the foothills, which are composed of younger detrital rocks. The range is bounded on the south by the narrow valley of Rivière Fer-à-Cheval, a prolongation of the Artibonite Valley. Along the trail from Belladère to Savanette the south slope of the range is much more precipitous than the north slope, descending from an altitude of 1,250 meters above sea level at the crest of the range to 535 meters above sea level at Savanette, only about 3 kilometers to the south.

Drainage.

The gorge of Rivière Artibonite, which cuts directly across the Montagnes Noires, and the abandoned gorge at Las Cahobas are the most conspicuous drainage features. The probable history of Rivière Artibonite is discussed on pages 381-382. In the northwestern part of the Montagnes Noires the drainage is almost completely controlled by the structure. Most of the streams flow either northwestward or southeastward, parallel to the strike of the rocks, and finally break across the outer ranges through deep, narrow gorges into the Artibonite Plain or the Central Plain.

ARTIBONITE PLAIN AND VALLEY.

NAME AND GENERAL FEATURES.

The name Artibonite Plain has been applied since early colonial days to the seaward flood plain and deltas of Rivière Artibonite and Rivière l'Estère, and to the contiguous flood plain of Rivière la Quinte, which is also known as the Gonaïves Plain. The name Artibonite Valley is here used for the part of the valley of the Artibonite above Petite-Rivière and its southeastward prolongation, the valley of Rivière Fer-à-Cheval. The plain and valley form a southeastward tapering wedge separating the Montagnes Noires from the Chaîne des Mateux and Montagnes du Trou d'Eau. Near the Dominican border the wedge tapers out, and the Montagnes Noires unite with the Montagnes du Trou d'Eau. Northwest of Mirebalais the valley trends N. 50° W., parallel to the inclosing mountains, but southeast of Mirebalais the trend of the valley and of the inclosing mountains changes to N. 70° W. The length of the plain and valley is about 120 kilometers, and the width decreases southeastward from a maximum of 30 kilometers near the sea.

LAND FEATURES.

Artibonite Plain.

The Artibonite Plain as defined in the preceding paragraph has a maximum altitude above sea level of not more than about 50 meters. Virtually all the region is covered with Recent alluvium, which near the sea forms a true plain. (See Pl. VI, *B*, p. 64.) The surface deposits consist principally of fine silt, but near the mountains there are beds of gravel and boulders. A large part of the plain is periodically flooded during the rainy seasons. As the entire region is semiarid it is not dissected rapidly, and the great quantities of silt deposited when the rivers overflow diminish the surface irregularities. An extensive playa flat between Gonaïves and Dessalines, east of Morne Grammont, apparently has no surface outlet. (See Pl. XXV, *B*, p. 334.)

Several isolated hills and a conspicuous ridge, Morne Grammont, rise above the surface of the plain in the northeastern part near the Montagnes Noires. These surface features are more fully described on page 384.

Artibonite Valley.

A narrow flood plain, at few places more than 1 or 2 kilometers wide, extends along the river from Petite-Rivière southeastward to Mirebalais. Its surface gradually rises southeastward and at Mirebalais is about 100 meters above sea level. On the north side of the river, in the region between Petite-Rivière and La Chapelle, a belt of low, rounded hills and remnants of a smoothly sloping terrace plain separate the flood plain from

the flanks of the Montagnes Noires. These hills and the terrace plain are the dissected remnants of a former flood plain. Near Petite-Rivière this higher flood plain is strongly dissected and includes an area, several kilometers wide, of low hills that rise perhaps 50 meters above the present flood plain. Farther southeast, near Savane-à-Roche, the higher flood plain is a dissected terrace. The outer edge of this terrace is 20 or 30 meters higher than the present flood plain and its surface rises rather steeply toward the base of the near-by mountains. The terrace material consists of gravels, and the surface is in many places strewn with boulders and cobbles. Part of this terrace is a smoothly sloping grass-covered savanna. (See Pl. XXX, *A*.)

On the south side of the river a conspicuous ridge adjoining the present flood plain extends from Verrettes past La Chapelle toward Mirebalais. The ridge consists of resistant coralliferous limestone dipping northeastward on the north flank of a secondary anticline toward the trough of the main syncline. The ridge rises to an altitude of 100 to 150 meters above sea level. Its inner slope is a steep escarpment, but its outer slope is a long dip slope. A long, narrow lowland separates the ridge from the base of the mountains. The lowland contains a series of stream valleys carved in soft marl and sandstone, which underlie the coralliferous limestone. The many small streams that drain this lowland originate in the mountains to the southwest and many of them are deflected into courses parallel to the Artibonite by the ridge of coralliferous limestone. All of them ultimately break across the ridge in deep, narrow gaps and reach the Artibonite. The lowland and escarpment are shown in Plate XXX, *B*. Southeast of La Chapelle the lowland and ridge are interrupted by Morne Saut d'Eau, which extends northward from the Chaîne des Mateux.

Southeast of Morne Saut d'Eau the width of the Artibonite Valley increases to 20 kilometers. The flood plain of the Artibonite is very narrow and discontinuous, as the river swings against bluffs cut in clay and marl of Miocene age. The ridge of northeastward-dipping coralliferous limestone is not so conspicuous in this area as it is northwest of Morne Saut d'Eau, but it persists in the ridge southeast of Mirebalais on which Fort Anglais is situated. At the fort the altitude of the ridge is 190 meters above sea level, 60 meters higher than that of the town. The Miocene rocks between Mirebalais and the foot of the mountains to the south are intricately dissected. The divides are covered with gravels deposited along the tributaries of the Artibonite at a time when the flood plain of the Artibonite stood at a higher level. Near the mountains these gravels are at an altitude of 250 meters above sea level. The town of Mirebalais stands on a gravel-covered bench at an altitude of 130 meters above sea level, or about 30 meters higher than the present flood plain.

A. GRAVEL-COVERED TERRACE IN THE ARTIBONITE VALLEY NEAR SAVANE-À-ROCHE.

B. LOWLAND OF MIOCENE MARL AND RIDGE OF MIOCENE CORALLIFEROUS LIMESTONE NEAR LA CHAPELLE.

The lowland is floored with marl arched in an anticline. The overlying coralliferous limestone dips northeastward toward Rivière Artibonite on the northeast limb of the anticline.

The surface features on the north side of the Artibonite from Mirebalais to La Chapelle resemble those on the south side and are the result of the erosion of rocks of different hardness that are arched in a secondary anticline parallel to the main syncline. A high ridge on the crest of the anticline corresponds to Morne Saut d'Eau on the south side but apparently is completely isolated from the Montagnes Noires. This ridge is surrounded by a narrow lowland, at the outer edge of which the Miocene coralliferous limestone crops out in a low, narrow ridge that has a long dip slope facing outward from the lowland and a steep escarpment facing inward. Softer rocks underlie the lowland between the low ridge and the narrow flood plain of the Artibonite. These rocks are intricately dissected. The divides are covered with gravels, which reach an altitude of 240 meters above sea level near the foot of the mountains.

All the surface features of the Artibonite Valley continue southeastward from Mirebalais along the valley of Rivière Fer-à-Cheval, which is underlain by the same rocks and is structurally part of the same northwestward-plunging syncline. The flood plain of Rivière Fer-à-Cheval is very narrow and is flanked by low rolling hills covered with gravels deposited at the same time as the gravels in the Artibonite Valley. On the south side of the river, between Mirebalais and the mouth of Rivière Gascogne, the highest of these hills has an altitude of 290 meters above sea level, or 60 meters above the level, grass-covered savannas bordering the hills near the river. The Miocene rocks of the Artibonite Valley extend up Rivière Gascoyne, a tributary of Rivière Fer-à-Cheval, and underlie the intricately dissected spurs along the base of the mountains.

East of Poste de Flandé, where the road from Mirebalais to Las Cahobas turns northward through the gap in the Montagnes Noires, the valley of the Fer-à-Cheval abruptly narrows and is hemmed in by the Montagnes Noires and a range that separates the Fer-à-Cheval and Gascogne valleys. The rocks in this narrow valley are the same as those in the Artibonite Valley but are more strongly folded. They underlie the grass-covered spurs that lead up to the more densely wooded and more rugged limestone mountains. The west end of the range between the valleys of Rivière Fer-à-Cheval and Rivière Gascogne is composed entirely of these Miocene detrital rocks. Farther east older limestone crops out in the central part of the range. The difference in surface features between the detrital rocks and limestone is strikingly shown in this range. The detrital rocks are more intricately dissected, but the slopes on the limestone are steeper and are scarred by cliffs.

About 4 kilometers west of Savanette a northward-trending arch brings the older limestone to the surface and for a distance of almost 2 kilometers Rivière Fer-à-Cheval flows in a gorge cut in older limestone. About 3 kilometers west of Savanette the Miocene rocks again

appear and they underlie the narrow river valley. Immediately west of Savanette the river cuts through a narrow ridge consisting of Miocene rocks folded into a narrow, asymmetric anticline. (See Pl. XXVI, *A*, p. 336.) This ridge extends southeastward across the valley and then eastward along the south side of the valley for a distance of about a kilometer east of Savanette. The slope of the mountains into the narrow valley is remarkably steep, especially on the south side.

Drainage.

Rivière Fer-à-Cheval and Rivière Artibonite below Mirebalais occupy the trough of a northwestward-plunging syncline. It seems that the drainage of the lower Artibonite was formerly limited to the drainage of this syncline. At that time the Central Plain drained southeastward toward the present Rio Yaque del Sur, and the volume of water in the system that comprised the Fer-à-Cheval and the Artibonite was much less than it is now. The gravels about 30 meters above the present flood plain were deposited at that time when the flood plain was much wider than it is today. The altitude of the gravels increases toward the mountains along the lateral streams. The trenching of this old flood plain is probably due to the greatly increased volume of water derived from the Central Plain through the Las Cahobas gap. (See pp. 381-382.) The valley of Rivière Fer-à-Cheval between Mirebalais and the Las Cahobas gap is much wider than the valley east of the gap and is the direct continuation of the Artibonite Valley below Mirebalais. These features of the Fer-à-Cheval valley support the conclusion that the Central Plain drainage formerly entered the Artibonite Valley through the Las Cahobas gap. The probable history of the second deflection of the Central Plain drainage to its present course across the Montagnes Noires is considered on page 382. Between the gorge and the mouth of Rivière Fer-à-Cheval the Artibonite is intrenched in the flood-plain deposits of the earlier Artibonite and its lateral streams.

The large number of streams that cut across the ridge of coralliferous limestone on the south side of Rivière Artibonite, between Verrettes and Morne Saut d'Eau, suggests that their course was determined during the time when the Artibonite flood plain was higher and when the valley was nearly leveled. The courses of these streams across the ridge that were uncovered during the renewed erosion were retained.

Shore Features.

The shore features of the Artibonite Plain are very uniform. Extensive mud flats, saline lagoons, and mangrove thickets extend from Gonaïves to the southern edge of the plain at Point Diable. The shore line is very irregular and is being continually modified by the deposition of sediments.

SUBLITTORAL FEATURES.

A shallow platform that has a minimum width of 4 kilometers extends along the shore line of the Artibonite Plain. The 20-fathom line at the outer edge of the platform is indented off Gonaïves Bay, but the head of this indentation is 11 kilometers from the head of the bay. The outer edge of the platform extends almost due southward from the head of this indentation to Pointe Diable, and the platform gradually narrows southward.

MONTAGNES DU TROU D'EAU.

NAME AND EXTENT.

The mountains on the north side of the Cul-de-Sac Plain and Étang Saumâtre are here called the Montagnes du Trou d'Eau. The name is derived from Morne Trou d'Eau, a conspicuous peak northeast of Thomazeau.

The Montagnes du Trou d'Eau lie between the Artibonite Valley and the Cul-de-Sac Plain, but near the Dominican border they merge into the eastward extension of the Montagnes Noires, forming the Sierra de Neiba of the Dominican Republic. From the Dominican border the Montagnes du Trou d'Eau trend about N. 70° W., but as they approach the sea their trend changes to N. 50° W., and although the mountains are continuous this part of the range is known as the Chaîne des Mateux. The length of the Montagnes du Trou d'Eau is about 50 kilometers. Their maximum width at the eastern end is 18 kilometers, but along the road from Port-au-Prince to Mirebalais their width is 8 kilometers.

SURFACE FEATURES.

Eastern Part.

From the Dominican border westward to Morne Trou d'Eau the surface rock is limestone. Basaltic volcanic rocks, which underlie the limestone, are exposed in some of the deep ravines on the north and south slopes of the mountains. Near Morne Trou d'Eau the mountains form a single range, the crest of which is close to the southern margin, overlooking the Cul-de-Sac Plain. Farther east the mountains are wider and are not clearly aligned in ranges.

Rounded spurs project from the mountains down to the edge of the plain, but the upper slopes are more rugged. Deep ravines gash the mountain front, but no through-flowing surface streams enter the plain from these mountains. Morne Trou d'Eau, which has an altitude of 1,385 meters above sea level as determined trigonometrically by the Service des Levés Topographiques, is the highest peak on the south side of the mountains. As seen from the plain its crest is rounded, but cliffy slopes lead down to a deep ravine, which severs it from the mountains

farther east. The trail from Thomazeau to Cornillon crosses the divide at the head of this ravine at an altitude of 820 meters above sea level.

The most striking surface features of the mountains northeast of Morne Trou d'Eau are due to solution of the limestone and to underground drainage. The village of Cornillon stands in a deep, narrow, flat-floored valley that has no surface outlet. At Cornillon the valley trends about N. 70° W. The valley drains eastward and westward toward the village, and during the rainy season surface water collects on the residual clay that forms the valley floor. The walls of the valley are steep and are scarred by cliffs. From the crest of the ridge on the south side of the valley a similar but wider depression that has no surface outlet is visible on the north side of the ridge that towers above Étang Saumâtre. The trail from Cornillon to St.-Pierre passes along the north side of another narrow depression that has no surface outlet. The floor of this depression is pitted by small basins, which probably coincide with the course of an underground stream. Near St.-Pierre and to the north, toward Savanette, the valleys are wide and the ridges more subdued. Cornillon has an altitude of 925 meters above sea level. Morne Napipe, the crest of a prominent ridge northwest of St.-Pierre, rises to an altitude of 1,520 meters above sea level, as determined trigonometrically by the Service des Levés Topographiques.

The trail from Cornillon to Mirebalais ascends a steep slope of bare, jagged limestone to the crest of a spur and crosses the divide at an altitude of 1,150 meters above sea level. At an altitude of 800 meters above sea level it plunges down a steep dip slope of limestone onto a gently sloping spur of folded detrital rocks that leads down into the valley of Rivière Gascoyne. This spur and similar spurs to the east and west are much more intricately dissected than the main mountain mass. The spurs are separated by deep ravines that contain running water.

Western Part.

From Morne Trou d'Eau westward to the eastern end of the Chaîne des Mateux the Montagnes du Trou d'Eau comprise a single narrow range that is not so high as the mountains farther east. The road from Port-au-Prince to Mirebalais approaches the mountains along a ravine but in a short distance leaves the ravine and ascends the steep slope of Morne à Cabrits to an altitude of 620 meters above sea level. It then descends into the same ravine at Fond-Diable. The steep grade on Morne à Cabrits might be avoided by constructing a road along the ravine, but the lower part of the ravine is very narrow and steep-walled. Morne Terre-Rouge, the crest of the range north of Fond-Diable, has an altitude of 880 meters above sea level, as determined trigonometrically by the Service des Levés Topographiques. Morne des Crochus, whose altitude is 1,170 meters, is the highest peak in the western part of the Montagnes du Trou d'Eau.

Drainage.

The Montagnes du Trou d'Eau are deficient in surface streams. The underground drainage in the eastern part is described on page 390. In the western part surface drainage is more clearly established, and deep ravines, which are dry during most of the year, drain northward and southward from the crest. Parts of the courses of these ravines are parallel to the strike of the rocks.

CHAÎNE DES MATEUX.

NAME AND EXTENT.

The mountains that extend southeastward from St.-Marc toward the Cul-de-Sac Plain are here called the Chaîne des Mateux, from the name generally given to their central part. As the mountains approach the Cul-de-Sac Plain their trend veers eastward, and beyond this turn the range is called the Montagnes du Trou d'Eau. The Chaîne des Mateux lies between the Artibonite Plain and the St.-Marc Canal. Its length is 75 kilometers and its average width 20 kilometers.

GENERAL FEATURES.

The trend of the mountain mass and of many of the surface features is about N. 50° W., parallel to the structural trend. Limestones are the surface rocks in the interior mountains, and younger limestone and detrital rocks underlie foothills on the flanks of the range. Basaltic volcanic rocks are exposed on the north slope of the mountains near Saut d'Eau.

The hills inclosing St.-Marc Bay, which may be called the Mornes de St.-Marc, and the narrow coastal plain at l'Arcahaie are included in the Chaîne des Mateux, but as they have entirely different features they are described under separate headings.

LAND FEATURES.

Chaîne des Mateux Proper.

The Chaîne des Mateux proper has an average altitude of 1,200 to 1,300 meters above sea level. Morne Batiste, the highest summit, rises to an estimated altitude of 1,575 meters above sea level. The chain includes several ranges and many isolated mountains. Rivière Mont Rouis flows almost due westward across the northern part of the chain and divides it into two ranges. The mountains on the north side of Rivière Mont Rouis overlooking the Artibonite Plain are frequently called the Montagnes des Verrettes. The valley of Rivière Mont Rouis is very deep and its slopes are broken by high cliffs. The mountains slope abruptly northeastward to the Artibonite Plain and southwestward to

the sea and the Arcahaie Plain. The northwest end of the chain rises steeply above the Mornes de St.-Marc to an estimated altitude of 1,200 meters above sea level, and the slope is scarred by towering dark cliffs.

The crest of the chain northeast of l'Arcahaie is a mountainous highland that has a range in relief of 200 to 300 meters. The slopes are relatively gentle, and the summits are rounded. This highland, unlike most other areas where limestone is the surface rock, contains no conspicuous cliffs. The profiles of the ridges at the outer edges of the highland are asymmetrical. Short, steep escarpments face inward from the summit of the ridges, and longer, more gentle dip slopes on beds of limestone face outward toward the flanks of the chain. Certain areas in the highland have sink holes arranged along depressions that probably coincide with the courses of underground streams.

A belt of foothills runs parallel to the mountains on both the northeast and the southwest side except along the coast between Mont Rouis and Pointe Trou Forban. The foothills consist of limestone and marl of Miocene age that at one time probably extended over the mountains but have been removed from the mountain crest by erosion. Inward-facing escarpments and outward-facing dip slopes are the most conspicuous features of the foothills.

The southeast end of the Chaîne des Mateux has a greater variety of surface rocks and surface features. Morne Saut d'Eau, the conspicuous ridge northwest of Saut d'Eau, is joined to the main mountains. Rivière Canot plunges over a high falls on the east slope of this ridge. On the southeast slope there is a remarkably level plateau at an altitude of 480 meters above sea level. The small stream that drains the plateau apparently has been diverted for irrigation, as it has no channel. It plunges over the edge of the plateau in a waterfall that is probably 80 meters high. Hugh masses of the marl that underlies the plateau break off along the crest of the waterfall. Southwest of Saut d'Eau two rolling, grass-covered savannas, Savane Madame Michel and Savane Madame Michaud, extend southwestward into the mountains. These savannas are underlain by basaltic volcanic rocks.

The interior highland of the Chaîne des Mateux is so slightly dissected, despite its altitude, that it probably has not long been exposed to erosion. The Miocene beds on the flanks of the chain probably extended across the crest of the mountains and have been removed, revealing the underlying limestone.

Mornes de St.-Marc.

The name Mornes de St.-Marc is here used for the hills that enclose St.-Marc Bay. They include Morne de l'Anse-à-l'Inde, the hills on the north side of the bay, and its southeastward prolongation, the Mornes des Guêpes. They are composed of the same rocks as the foothills of

the Chaîne des Mateux proper and are essentially the continuation of the foothills around the plunging crest of the main anticline. These rocks are more readily eroded than the rocks that underlie the Chaîne des Mateux proper. Structurally the Mornes de St.-Marc comprise two anticlines that plunge northwestward and are separated by a similarly plunging syncline. The outline of the coast is determined by these three structural features. The promontories on both the north and the south side of the bay, which coincide with the crests of the anticlines, are beveled by several emerged coastal terraces.

The Mornes de St.-Marc are much lower and less rugged than the adjacent slopes of the Chaîne des Mateux proper. Their summits rise to altitudes of 300 to 350 meters above sea level. The entire region is strongly dissected and comprises almost equal areas of hills and lowlands. The hills are capped by coralliferous limestone that overlies the marls in which the valleys are cut. The limestone is much harder than the marl, and wherever the streams reach the marl they establish a grade quickly and rapidly broaden their valleys by undercutting the limestone, which stands up in steep slopes or cliffs bordering the valleys. There are three valleys, or really lowlands, in this region. One of these lowlands has been eroded on the crest of the anticline in the Mornes des Guêpes, north of St.-Marc, and is traversed by the road from St.-Marc to Gonaïves. It is completely surrounded by a rim of limestone, but the stream escapes southwestward through a gorge. Another lowland coincides with the trough of the syncline and extends southeastward from St.-Marc. It is drained by two small streams that flow northwestward into the bay. The third lowland is on the crest of the anticline south of St.-Marc. Its drainage escapes northward and southward through gorges in the encircling limestone hills. The road from Port-au-Prince to St.-Marc follows these gaps. The encircling hills rise from 100 to 200 meters higher than the lowlands.

Arcahaie Plain.

The Arcahaie Plain is a narrow alluvial coastal plain that has a maximum width of 6 kilometers and a length of almost 28 kilometers. It is separated from the northwest end of the Cul-de-Sac Plain by foothills of the Chaîne des Mateux that extend almost down to the shore line. The plain wedges out to the northwest, where the steep slopes of the mountains reach the sea. Near the shore line the plain is low and barely dissected. The landward part slopes more steeply and is dissected by ravines. The maximum altitude of the plain near the base of the mountains is about 150 meters above sea level. The plain clearly owes its origin to the deposition of sediments on the shallow sublittoral platform that extends northwestward as far as the plain.

Drainage.

In the interior highland of the Chaîne des Mateux proper the streams originate in valleys that run roughly parallel to the strike of the rocks. After flowing parallel to the structural trend they break across the ridges on the outer sides of the highland and plunge down the steep slopes of the mountains in deep V-shaped ravines. The relief on the outer border of the mountains is much greater than in the highland, and the slopes are far more rugged.

The streams on the anticlines of the Mornes de St.-Marc apparently are superimposed on the structure.

Shore Features.

Between the south edge of the Artibonite Plain and Mont Rouis the shore line is bordered by the Mornes de St.-Marc. This shore line is clearly a shore line of emergence, and steeply sloping emerged coastal terraces are the most conspicuous shore features. St.-Marc Bay is a broad U-shaped indentation coinciding with a northwestward-plunging syncline. Except at the head of the bay, the shore line is bordered by an almost continuous sea cliff, 20 to 30 meters high. This cliff is the seaward face of the lowest terrace. On the south side of the bay the altitude of the outer edge of the lowest terrace is about 35 meters above sea level and that of the second about 100 meters. On Cap St.-Marc there are four well-defined terraces, but the upper two were not examined. The width of the lower terraces increases to a maximum of between 1 and 2 kilometers on Cap St.-Marc. On both the north and the south coast of the cape the width decreases. The terraces on the north side of St.-Marc Bay appear to correspond to those on the south side. Pointe Diable is the western extremity of a small table-land, part of the lowest terrace, isolated by mud flats which may indicate a former channel of Rivière Artibonite.

The head of St.-Marc Bay is bordered by a narrow fringe of alluvium. The hills at the edge of the fringe are not terraced like the hills along the north and the south side of the bay. Southeast of Cap St.-Marc the coastal terraces become lower and narrow. There are no conspicuous terraces southeast of Bois-Neuf, but at Mont Rouis recently emerged coralliferous limestone is found at an altitude of 10 meters above sea level.

From the mouth of Rivière Mont Rouis southeastward almost to Pointe Trou Forban the sea washes the steep unterraced slopes of the Chaîne des Mateux. The shore line is bordered by a narrow fringe of detritus derived from the limestone cliffs. From Pointe Trou Forban southeastward to Boucassin the shore is bordered by the Arcahaie Plain, which is gradually extending seaward. Foothills of the Chaîne des Mateux extend along the coast from Boucassin southeastward to the northwest extremity of the Cul-de-Sac Plain.

SUBLITTORAL FEATURES.

Between Pointe Diable and Mont Rouis the sublittoral platform is very narrow, like that along other shores of emergence. The 20-fathom line closely parallels the shore line around the indentation of St.-Marc Bay. At the head of the bay it is only 300 meters distant from the shore. Between Mont Rouis and Pointe Trou Forban the platform is even narrower. The steep sublittoral slope conforms to the steep slope of the mountains above the shore line. Off Pointe Trou Forban the 20-fathom line bends southwestward toward the southeast end of Gonave Island along the outer edge of the extensive platform described on page 398.

CUL-DE-SAC PLAIN.

NAME AND EXTENT.

The Cul-de-Sac Plain is perhaps the most striking surface feature of the Republic. When the early settlements were established at Petit-Goave and near the present site of Léogane the huge gulf between the two westward-extending peninsulas of the Republic that has its apex in Port-au-Prince Bay was called the Cul-de-Sac. The name was finally restricted to the plain at the apex of the cul-de-sac. The plain itself is not a cul-de-sac but part of a remarkable depression extending from Port-au-Prince Bay southeastward across the island to Neiba Bay. The part of the depression within the limits of the Dominican Republic is called the Hoya de Enriquillo. This depression contains the two largest lakes in the island, Étang Saumâtre and Lago de Enriquillo, both of which have no outlet.

The plain is rectangular in outline. Its length from the shore of Port-au-Prince Bay southeastward to Etang Saumâtre is about 30 kilometers, and its average width is about 16 kilometers.

GENERAL FEATURES.

The Cul-de-Sac Plain is a deep trough, bounded on the north and south by high mountains. The plain stands at an average altitude of not more than 50 meters above sea level—so low that when seen from a distance, as from Gonave Island, it looks like an arm of the sea. It trends about N. 75° W., parallel to the trend of the inclosing mountains and to the strike of the older rocks.

LAND FEATURES.

Outline and Dominant Elements.

The outline and principal surface features of the plain are shown on Plate XXXIX (p. 516). The plain has a general northward slope that extends almost to the very base of the mountains on the north side. A

low north-south divide in the eastern part diverts a part of the drainage eastward into Étang Saumâtre and a larger part westward toward the sea. A shallow depression near the middle of the northern part of the plain contains a small fresh-water lake called Trou Caïman, which is said to overflow occasionally during floods down Ravine Boucan Brou to the sea. During years of abnormally low rainfall Trou Caïman is smaller than it appears on Plate XXXIX. A much larger depression at the eastern extremity of the plain contains the brackish-water lake called Etang Saumâtre. Its level is higher during years of heavy rainfall than it was during the winter of 1919-20, which was preceded by several years of low rainfall. In 1900 the surface of Étang Saumâtre was 20 meters above sea level, according to levels run from Port-au-Prince.[1] At the same time the similar but larger and saltier lake in the Dominican Republic, Lago de Enriquillo, was 34 meters below sea level.[2] Along the north side of Étang Saumâtre high mountains rise abruptly from the edge of the water. Along the south side, west of Fond-Parisien, a ridge separates the lake from the mountains, but near the Dominican border the mountains extend down to the lake.

The surface of the plain consists of alluvium washed down from the inclosing mountains. As the only through-flowing surface streams that carry water to the margin of the plain emerge from the mountains on its south side, more alluvium has been deposited on that side, and this fact accounts for the northward slope of the plain. This slope is greatest near the southern border of the plain and decreases northward. The northern half of the plain is very flat and but little dissected, but along the southern margin of the plain ravines attain a depth of several meters. Grande Rivière du Cul-de-Sac near Bassin Général is intrenched to a depth of almost 10 meters. This dissection along the southern side of the plain is hardly more than sufficient to accommodate flood waters. Foothills composed of strongly folded detrital rocks of Miocene age and younger imperfectly consolidated gravels extend into the plain from the mountains along the south side. Fort National is situated on one of these foothill ridges, which partly incloses Port-au-Prince. The dwelling houses of the Haytian-American Sugar Co. are built on the northern end of this ridge.

About 4 kilometers southeast of Croix-des-Bouquets, near Peyrard, a low northwestward-trending ridge rises 10 or 20 meters above the surrounding plain. It is composed of cemented gravels and probably is a remnant of older alluvial deposits that were laid down along a former channel of Rivière Blanche and has since been isolated by erosion. Ridges of a similar appearance as seen from the plain flank the present channel of Rivière Blanche near the southern margin of the plain.

[1] Tippenhauer, L. G., Beiträge zur Geologie Haïtis, V: Petermanns Mitt., Band 47, p. 170, 1901.

[2] Tippenhauer, L. G., idem, p. 169.

Foothills composed of coralliferous limestone of Quaternary age extend along parts of the southern and northern margins of the eastern part of the plain. This limestone was deposited when the entire trough was a strait separating the island of Haiti into two major parts. Just north of Trou Caïman the limestone forms irregular, narrow benches that extend to altitudes of 50 or 75 meters above the surface of the lake. Similar limestone underlies the prominent ridge that projects northward into the Étang Saumâtre between Gantier and Fond-Parisien. Along the trail between these two villages the ridge attains an altitude of 125 meters above sea level, and it is higher near the lake. The northwestward-extending ridge south of Sources Despuzeaux, which was not examined, probably is composed of the same limestone.

Other features of the plain that are significant with regard to the supply of water are described on page 515.

The surface features of the Cul-de-Sac Plain are due almost entirely to Quaternary alluviation. The depressions occupied by Étang Saumâtre and Trou Caïman are most likely due to the same cause, although their formation probably began during the time when the sea covered the site of the plain, before the period of subaerial alluviation. The sediments deposited in the sea at that time by streams corresponding more or less closely to the present streams were unevenly distributed on the sea bottom, and the areas that received the smallest amount of sediments became basins that remained as lakes when the sea withdrew. The semiarid climate that characterizes the plain would preserve rather than destroy these depressions because the quantity of surface water is not sufficient to support through-flowing streams and permit the establishment of an unbroken drainage system.

Shore Features.

Alluviation has largely determined the form of the shore features of the plain. Mud flats and mangrove swamps extend along the entire shore line. Barren saline flats back from the coast are occasionally flooded by sea water. Small mangrove islets lie off the shore.

SUBLITTORAL FEATURES.

The peculiar features of the Cul-de-Sac Plain are not confined to its subaerial part. The soundings recorded on chart No. 2656 of the Hydrographic Office of the United States Navy reveal a submerged part of the plain that is remarkably similar to the subaerial part. (See Pl. XXXI.) The submerged part of the plain bends northwestward parallel to the trend of the Chaîne des Mateux and the lower Artibonite Valley. It extends as far as a line drawn from the southeastern end of Gonave Island to Pointe Trou Forban. Its length is 45 kilometers and its maximum width is 32 kilometers. It comprises a flat plain and an

inclosed basin having relations to each other like those of the Cul-de-Sac Plain to the basin of Étang Saumâtre. The plain is part of the sublittoral platform that borders the coast of other parts of the Republic. The maximum depth of water on the flat part of the platform is 20 fathoms (37 meters), but the mean depth is about 17 fathoms (31 meters). Tongues on which the maximum depth is 10 fathoms (18 meters) extend southeastward and northeastward from the southeastern end of Gonave Island along the outer edge of the platform. Smaller ridges encircled by the 10-fathom contour rise above the surface of the platform. The small, low islands called Les Arcadins rise above the surface of the water on one of these ridges. The platform is widest between the northern coast of the Lèogane Plain and the southeastern coast of Gonave Island and off the coast of the Arcahaie Plain. The outline of the platform is very irregular in the harbor of Port-au-Prince, where numerous cays and shoals rise above the surface of the water or lie awash. The outer edge of the platform slopes steeply into deep water. The length of the basin inclosed by the platform from a point south of Les Arcadins to the harbor of Port-au-Prince, is 35 kilometers, and its width is 17.5 kilometers. The maximum depth of water recorded in the basin is 85 fathoms (155 meters).

An emergence of 25 fathoms (46 meters) would unite Gonave Island with the mainland and add an extensive area to the Cul-de-Sac Plain. This area would contain a lake larger than Étang Saumâtre that would resemble the lakes in the subaerial part of the plain.

The platform probably owes its origin to base-leveling at a time when the land stood higher. The basin may have been outlined even at that time, and it may have been accentuated by unequal sedimentation during the Quaternary submergence, although it is difficult to account for rapid sedimentation across the northwest end of the platform. Inequalities on the platform have been and still are being planed off by wave erosion subsequent to the emergence that is known to have affected the subaerial part of the plain.

MASSIF DE LA SELLE.

NAME AND EXTENT.

The name Massif de la Selle, which is derived from Mont La Selle, its highest peak, is used here for the mountainous area in the southeastern part of the Republic. Geographers have used the name Montagne de la Selle for the range of which Mont La Selle is a part, but no name has heretofore been given to the entire mountainous complex.

The Massif de la Selle is the northwestward prolongation of the Sierra de Bahoruco of the Dominican Republic. The western boundary of the massif is not well defined, but between Jacmel and Grand-Goave the mountains are low, and as the geologic history of the more mountainous

region to the east differs from the history of the mountainous region to the west, this break is taken as the boundary.

The area included in the Massif de la Selle is 100 kilometers long and has an average width of 30 kilometers.

GENERAL FEATURES.

Most of the Massif de La Selle is extremely mountainous. The largest coastal plain in this region, Léogane Plain, is on the north coast, and a narrow lowland extends almost continuously from this plain eastward to Port-au-Prince, where it merges into the Cul-de-Sac Plain. On the south coast there are very small coastal plains at Jacmel, Cayes de Jacmel, Saltrou, and Anse-à-Pitre. A narrow lowland extends along the south coast from Jacmel eastward to the mouth of Rivière de Fesle near Marigot.

The surface trends of the Massif de la Selle coincide approximately with the northwestward strike of the older rocks except where undeformed younger rocks overlap the older rocks.

LAND FEATURES.

Mountains.

NORTH SLOPE.

The mountains on the north slope of the Massif de la Selle rise boldly above the Cul-de-Sac Plain. They are composed mainly of limestone but certain spurs at their bases are composed of younger detrital rocks. The contrast between the two groups of rocks is sharply defined, as the slopes of the limestone terrane are much steeper but less intricately dissected.

South of Port-au-Prince is a narrow, steep ridge called Morne Hôpital, which, as determined trigonometrically by the Service des Levés Topographiques, rises to an altitude of 1,040 meters above sea level, towering above the city. The ridge trends about N. 75° W., parallel to the strike of the rocks. The upper part of the northern slope is very steep and conforms closely to the steep northward dip of the rocks. South of the ridge and approximately parallel to it is the deep, narrow valley of Rivière Froide. To the west, where the ridge is lower, it is crossed by Rivière Froide in a narrow gorge. The prolongation of the ridge farther west strikes into the Léogane Plain. Toward the east Morne Hôpital loses its identity, but the first ridge between Pétionville and the gorge of the Grande Rivière du Cul-de-Sac is essentially its prolongation. The first ridge east of the Grande Rivière du Cul-de-Sac reaches an altitude of 984 meters above sea level in Morne des Enfants Perdus, as determined trigonometrically by the Service des Levés Topographiques. Eastward from Morne des Enfants Perdus the front range

apparently consists of several ridges aligned parallel to the strike of the rocks.

The trail from Pétionville to Furcy crosses the crest of a second ridge about 5 kilometers south of Pétionville at an altitude of 1,200 meters above sea level. Fort Jacques, which, as determined trigonometrically by the Service des Levés Topographiques, has an altitude of 1,340 meters above sea level, stands on the eastward prolongation of this ridge. The ridge terminates south of Morne Hôpital on the north side of the valley of Rivière Froide.

The mountains on the north slope of the massif owe some of their peculiar surface features to solution of the limestone by ground water. On the crest of the first ridge southeast of Fond-Parisien the trail to Fond-Verrettes crosses a shallow elliptical depression, apparently a sink hole. The floor of this depression, like that of most sink holes, has a thick covering of fertile soil, most of which is cultivated. The longer axis of the depression is parallel to the strike of the rocks. Fond-Verrettes, also called Mission, stands 810 meters above sea level, in a narrow U-shaped valley, the sides of which rise steeply to perhaps 250 meters above the valley floor. The valley parallels the northwestward strike of the rocks and probably has been widened and deepened by solution. Near the east end of Morne Hôpital a small, deep sink hole was seen. About 1 kilometer southeast of Rendez-vous there is a wide, deep sink hole, the floor of which is under intensive cultivation. A small sink hole was seen only a few hundred meters south of the crest of the mountains at an altitude of nearly 1,700 meters, on the trail from Fond-Parisien to Grand Gosier.

INTERIOR.

Eastern Part, Including Montagne de la Selle.

The highest mountains in the Massif de la Selle are in the interior. The surface features of the eastern and western parts are quite different. The surface features of the eastern part are relatively simple, apparently because the entire region is composed of limestone. The limestone is folded and generally strikes north of west. The dominant feature of the region is a high, narrow central range known as Montagne de la Selle, the summit of which, Mont de la Selle, as determined trigonometrically by the Service des Levés Topographiques, stands 2,680 meters above sea level and, according to all available information, is the highest point in the Republic. Mont de la Selle is not a clearly isolated peak but rather a broad eminence. The profile of the mountain, viewed from the north, is fairly smooth, showing a gradual slope eastward to the Dominican border but a somewhat steeper slope westward. During the rainy season Mont de la Selle is hidden most of the time by clouds.

Deep ravines separated by high ridges furrow the steep north and south slopes of Montagne de la Selle. The trail from Fond-Parisien to

Grand-Gosier crosses the divide at an altitude of 1,700 meters above sea level. On the north slope it ascends from an altitude of 810 meters at the valley of Fond-Verrettes to an altitude of 1,500 meters in a distance of about 7 kilometers. On the south slope it descends from 1,500 meters to 950 meters in a distance of about 5 kilometers. Near the crest the slopes are not so steep.

Western Part.

The surface features of the mountains in the western part of the interior of the massif are more varied than those in the eastern part because the surface rocks are more varied and the structural features are more complex. The surface rocks include basaltic volcanic rocks and limestone, and the structure is complicated by faulting. The region comprises a wide central highland of basalt flanked on the north and south by still higher limestone ranges.

The lofty limestone range on the north side of the area of basalt forms the sky line as seen by an observer stationed in the Cul-de-Sac Plain. On some maps this range is designated the Montagne Noire, but this range should not be confused with the Montagnes Noires of the Département de l'Artibonite (see p. 382). In general features this range resembles Montagne de la Selle. Its crest along the trail from Pétionville to Furcy has an altitude of 1,680 meters above sea level. The highest peaks, Morne Tranchant (altitude 1,926 meters) and Morne Noir (also called Morne Pays-Pourri; altitude 1,805 meters as determined trigonometrically by the Service des Levés Topographiques) are on the crest of the range west of the Furcy trail. East of the Furcy trail the range is less conspicuous and west of Morne Noir its height diminishes until it is hardly recognizable west of the gorge of Rivière Momance. The deep valley of Rivière Froide separates this range from Morne Hôpital. The crest of the range trends about N. 70° W.

The central area is about 60 kilometers long and has a maximum width of 16 kilometers. It comprises probably the most rugged mountains of the Republic. The characteristic feature of the area is its intricate dissection in a complex dendritic pattern. Long flat-topped spurs extend southward a little distance into this region from the foot of Montagne Noire. The village of Furcy is on such a spur at an altitude of 1,520 meters above sea level. In the main body of the area the flat-topped spurs are replaced by knife-edge divides, which separate the lateral streams, tributaries of the Rivière Momance. The valleys and ravines are deep and V-shaped. The maximum relief in the region southeast of Furcy is about 700 meters. Precipitous rock slopes are common at the heads of ravines and there are numerous waterfalls. Trails plunge abruptly several hundred meters down into ravines.

The surface is equally rugged along the trail that ascends Rivière Gosseline from Jacmel to Port-au-Prince. This trail leaves Rivière Gos-

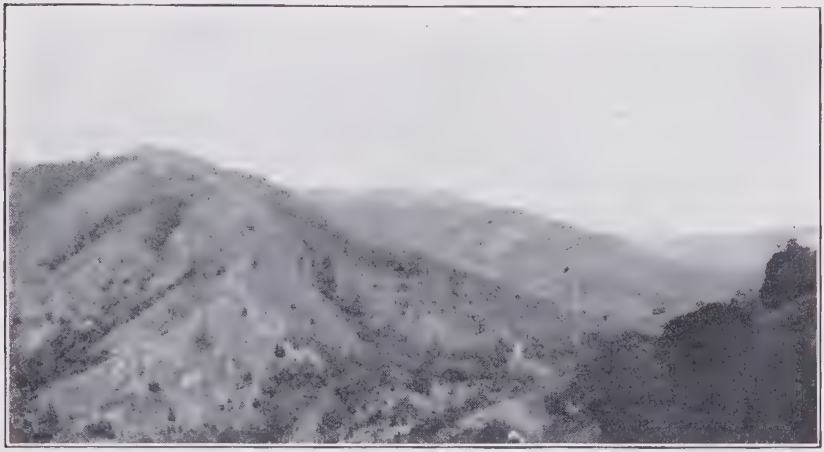
seline at an altitude of 240 meters above sea level and follows Rivière Mabial to an altitude of 450 meters; then, within a distance of 6 kilometers, it ascends to 1,330 meters above sea level on the crest of the divide between Rivière Gosseline and Rivière Momance. Westward from this trail the mountains are lower but are as intricately dissected as the higher mountains farther east. (See Pl. XXXII, *A*.) The main trail from Jacmel to Port-au-Prince, which follows the Grande Rivière de Jacmel, crosses the divide at an altitude of 400 meters above sea level. These mountains extend northward to the Léogane Plain.

On the south a high range overlooks the area of basalt as far west as the longitude of Port-au-Prince. It has a general east to west trend, but its western part appears to consist of segments arranged *en échelon*, which strike northwestward into the area of basalt and terminate along abrupt scarps. A segment southeast of Furcy culminates in Morne Cabaio (also called la Fenêtre), which has an altitude of 2,280 meters above sea level, as determined trigonometrically by the Service des Levés Topographiques. The last segment ends abruptly about 10 kilometers west of Morne Cabaio. Its summit, which has an estimated altitude of 2,000 meters above sea level, overlooks the rugged mountains in the area of basalt both to the north and west. The prominent white cliffs on its slopes indicate that this range, like that on the north side of the area of basalt, is composed of limestone.

SOUTH SLOPE.

On the south slope of the massif the mountains extend almost or quite to the shore line. On this slope, as in the interior, the variety of surface rocks and of surface features is greater in the western than in the eastern part. The mountains are not so clearly aligned in ridges as in the interior and on the north slope, and the relation between the structural trends and surface features is correspondingly less distinct.

The entire region east of Marigot is very rugged, and mountains of limestone descend to the coast. The maps show a trail following the coast from Grand-Gosier to the Dominican border, but such a route could be traversed only on foot. Between the settlement called Adieu-au-monde and Saltrou the trail in use leaves the coast to avoid high sea cliffs. It extends almost due east from Grand-Gosier to Banane on Rivière Pédernales and thence follows the river down to Anse-à-Pitre. The highest ridge crossed by the trail is 680 meters above sea level. West of Banane the trail follows a narrow U-shaped valley that trends about N. 60° W., parallel to the strike of the rocks. This valley, like so many other narrow strike valleys in limestone terranes in other parts of the Republic, has probably been widened and deepened by solution along bedding planes. The ridge on the south side of the valley has a very jagged crest.



A. VIEW OF THE CITRONNIERS VALLEY LOOKING NORTHWARD FROM A LOCALITY A FEW KILOMETERS NORTH OF THE CREST OF THE MOUNTAINS ALONG THE TRAIL FROM JACMEL TO LÉOGANE.

The rocks are basaltic lavas.

B. JAGGED LIMESTONE RIDGE ON THE NORTH SIDE OF THE MAPOUX PLAIN, GONAVE ISLAND.

Between Marigot and Jacmel the surface features are more diversified. The mountain slopes are separated from the sea by a narrow lowland. Small grass-covered conical hills composed of basalt border the Cayes de Jacmel Plain, especially on the northwest side. Back of these hills are steep mountain slopes, which at many localities rise in sheer cliffs. A lowland extends northwestward from Jacmel up the valley of Rivière Gauche. It coincides with the area of a marine embayment that was filled with coarse sediments during Pliocene time.

Plains.

Léogane plain.

The Léogane Plain is the only large plain within the area of the Massif de la Selle. It is rectangular in outline and has a length from east to west of about 12 kilometers and a maximum width of 10 kilometers. It lies across the northwest ends of the mountains on the north slope of the massif. The floor of the plain consists of alluvium deposited by Rivière Momance and Rivière des Citronniers on a platform that is genetically related to the submerged platform extending northwestward to Gonave Island. The plain evidently owes its origin to sedimentation on this platform, and it is being continually enlarged northwestward along the shallow outer margin of the platform.

Drainage.

The interior mountains of the massif form a divide from which the streams flow either into Port-au-Prince Bay and the Gonave Canal, to the north and northwest, or into the Caribbean Sea, to the south. At some places the stream courses are controlled by the structure. Rivière Momance, the largest stream, rises in the central area of basalt, where it receives many tributaries, flows almost due northward across the westward prolongation of Montagne Noire, and then turns abruptly westward, emerging on the Léogane Plain along the fault contact between the basalt and limestone. Rivière Froide rises on the north slope of the Montagne Noire near Rendez-vous, flows northwestward approximately parallel to the strike of the rocks and then turns northward, piercing the westward prolongation of Morne Hôpital in a narrow gorge. Rivière Momance and Rivière Froide are not more than a kilometer apart where their courses change direction, but they are separated by a narrow ridge whose crest is about 30 meters above the bed of Rivière Momance and 65 meters above Rivière Froide.

The south slope is not so well watered as the north slope except near Jacmel, where the mountains are much lower and the rain-bearing winds from the northeast are less completely robbed of their moisture than in other parts of the massif. Rivière Gauche, a tributary of Grande Rivière de Jacmel, the largest stream on the south slope, flows southeastward

in the narrow basin of Pliocene rocks near Jacmel. Rivière Adieu-au-Monde, a very small stream, is the only through-flowing stream between Rivière de Fesle and the Dominican border, where Rivière Pédernales reaches the sea.

Étang Bossier is a small lake on the south slope of the mountains about 5 kilometers northwest of Cayes de Jacmel. It has been described as a crater lake, but there is no evidence to support such a conclusion. It occupies a depression in the irregular topography along the contact between limestone on the east and basalt on the west. In November, 1920, the surface of the lake was about 10 meters lower than the possible outlet toward the Cayes de Jacmel Plain.

SHORE AND SUBLITTORAL FEATURES.

North Coast.

SHORE FEATURES.

Rapid alluviation has been the principal factor in determining the shore features of the north coast from Port-au-Prince westward to Grand-Goave. Long stretches of the shore are bordered by a fringe of mangrove thickets. Barren mud flats lie back of the mangrove thickets at several localities, especially near Grand-Goave. The alluvial fringe is widest at the mouth of Rivière Froide and at the Léogane Plain, where it extends far into the interior.

The alluviation has accompanied and followed emergence of the shore line. Evidence of emergence is afforded by marine sediments of Quaternary age. Such sediments were seen near Trou Jean Roger and at a point 0.5 kilometer east of Grand-Goave. At both places the marine beds seem to be remnants of a narrow terrace that rose 30 to 40 meters above sea level. The seaward face of the terrace is a sea cliff, the base of which is only a few meters above tide and less than 100 meters back of the shore line. At other localities imperfectly consolidated gravels, which probably are of the same age as the marine beds, have been dissected by the present streams.

SUBLITTORAL FEATURES.

The sublittoral features of the north coast from Port-au-Prince to Léogane are described on pages 397-398. Between Léogane and Grand-Goave there is a narrow sublittoral platform.

South Coast.

SHORE FEATURES.

Jacmel Bay is the largest indentation along the south coast of the massif. At the head of the bay there is a small alluvial plain built by Grande Rivière de Jacmel and Rivière des Orangers. Prominent sea cliffs extend along both sides of the bay. On the west side of the bay the cliffs

that extend around Cap Jacmel are about 9 meters high. They truncate coralliferous limestone of Quaternary age. Between Cap Jacmel and the head of the bay cliffs that have a maximum height of 70 meters truncate promontories composed of older limestone. Cliffs that have a maximum height of 12 meters extend along the east side of the bay from the town to Cap Maréchaux. These cliffs truncate a terrane of marine and non-marine beds of Quaternary age that extends eastward from Jacmel to Au Banc Poste, where a low ridge from the mountains reaches the sea. A small alluvial plain extends back from the coast at Cayes de Jacmel. Between Cayes de Jacmel and Marigot a narrow beach fringes the shore. The town of Marigot stands at the west end of an alluvial fill at the mouth of Rivière de Fesle.

The shore features change eastward from the mouth of Rivière de Fesle. As far eastward as Adieu-au-Monde there are sea cliffs separated by small coves with bayhead beaches. Between Adieu-au-Monde and Saltrou the sea cliffs are almost continuous. Saltrou stands on a small alluvial apron. Between Saltrou and the Dominican border high ridges truncated by lofty sea cliffs descend to the shore. Three kilometers northwest of Grand-Gosier the cliffs are 200 meters high. Grand-Gosier stands about 10 meters above sea level. Along the shore a thin veneer of imperfectly consolidated subangular beach shingle covers the bedrock between the cliffs. In the first cliff west of Grand-Gosier a thickness of about 10 meters of this beach shingle is exposed.

A similar shore line from which the mountains rise abruptly continues from Grand-Gosier southeastward to the plain at Anse-à-Pitre, on the Dominican border. The international boundary straddles the plain, which extends about 5 kilometers inland and which along the Haitian coast has a width of about 4 kilometers. It is one of the most desolate regions in the Republic; its only vegetation is cactus and spiny leguminous shrubs. It is unlike the other small plains on the south coast in that only its seaward margin is covered with alluvium. The remainder is floored with pitted brecciated limestone, which at some places is concealed by a thin covering of soil. The inner part of the plain has an altitude of 75 meters above sea level and Rivière Pédernales is intrenched about 15 meters below its surface. This plain apparently is an emerged and tilted wave-cut abrasion platform. On the western or Haitian side of the frontier it is bounded by a low ridge composed of the same bare, jagged brecciated limestone that floors the plain. About 3 kilometers northwest of Anse-à-Pitre the low ridge on the west extends to the shore and is truncated by sea cliffs. Small patches of firmly cemented beach pebbles and fragments of the shells of mollusks, especially *Strombus gigas,* are plastered against the cliffs up to an altitude of 10 meters above sea level. These patches of beach pebbles indicate the most recent emergence of the coast. The plain probably was formed during several periods of emergence, as several emerged coastal terraces are visible far to the southeast in the Dominican Republic.

The shore features of the south coast of the Massif de la Selle are not so homogeneous as those of some of the other geographic divisions of the Republic, but the evidence of recent emergence is clear. Areas of Quaternary marine rocks are extensive only in the region near Jacmel, where they reach an altitude of 65 meters above sea level. Farther east, where mountains border the coast, the emergence apparently has not been so great except near the Dominican border, although at almost every locality where the shore was seen there is evidence of an emergence of about 10 meters.

SUBLITTORAL FEATURES.

The sublittoral platform that parallels the shore around the indentation of Jacmel Bay is very narrow, indicating that the bay is the submerged part of the southeastward-plunging trough, which during Pliocene time was a bay that extended far inland toward the northwest.

Between Jacmel and Marigot the sublittoral platform is narrow. East of Marigot it is wider and attains a maximum width of 10 kilometers, as limited by the 20-fathom line. Along this part of the coast the outline of the platform is more irregular than it is farther west. It seems unreasonable to assume that so wide a platform has been planed off by wave erosion since the emergence of about 10 meters, but as an emerged wave-cut platform is not exposed at the foot of the cliffs it is assumed that the water on the platform was about 10 meters deeper before the emergence.

The slope from the outer edge of the platform into deep water is very abrupt. Within a distance of 1.5 kilometers from the outer edge of the platform a depth of 1,095 fathoms (2,002 meters) is recorded. The maximum recorded depth near the shore, 2,245 fathoms (4,106 meters), is only 15 kilometers from the outer edge of the platform.

MASSIF DE LA HOTTE.

NAME AND EXTENT.

The name Massif de la Hotte is here applied to the area that embraces most of the long Southern Peninsula and is derived from the name of the highest mountains in the region, the Montagnes de la Hotte, which are in its western part. The Massif de la Hotte is imperfectly separated from the Massif de la Selle by a narrow gap that extends from Jacmel to Grand-Goave, and there is no abrupt change in the surface features of the two regions. The massif is about 185 kilometers long and has an average width of 35 kilometers.

GENERAL FEATURES.

The Massif de la Hotte is the largest geographic province in the Republic to which a separate name has been applied. It contains a great variety of surface features, and is divisible into prominent surface units that are here described as separate subdivisions.

The massif is divided into two mountainous parts by the gap that is traversed by the road from Miragoâne to Aquin, whose crest has an altitude of 300 meters above sea level. East of the gap the crest of the peninsula has an average altitude of about 1,000 meters above sea level. West of the gap mountains attain a maximum altitude of perhaps 2,000 meters in the Montagnes de la Hotte.

LAND FEATURES.

The Massif de la Hotte is here divided into an eastern and a western part. The eastern part comprises two-thirds of the massif, including all the narrow part of the peninsula, and extends westward to an arbitrary line drawn from the eastern edge of the Cayes Plain northward to the valley of Rivière des Baradères. The western part embraces the wider western third and contains the highest mountains.

Eastern Part.

The surface features of the eastern part of the massif are very diversified. Some areas having more or less definite boundaries are characterized by distinctive features and are given separate names.

NORTH SLOPE.

A narrow coastal ridge that is divided into two parts by Petit-Goave Bay extends from Grand-Goave westward to Miragoâne, embracing Tapion du Petit-Goave and Tapion de Miragoâne. Both Tapions trend about N. 70° W. Tapion du Petit-Goave has a maximum altitude of about 400 meters above sea level and is imperfectly isolated from the mountains to the south by the gap that is traversed by the road from Port-au-Prince to Miragoâne, where the crest of the gap is about 180 meters above sea level. Tapion de Miragoâne rises to an altitude of about 600 meters above sea level. It has a serrate crest and steep slopes. The south slope is shorter and steeper than the north slope. It is separated from the mountains to the south by a deep, narrow trough, the western part of which contains Étang de Miragoâne. The eastern part of the trough drains into Baie de Petit-Goave, but the lake drains northward. The floor of the trough consists of basalt, which is in places covered with alluvium. The trough apparently coincides with the crest of an anticline, and the steep southward slope of Tapion de Miragoâne and the similar northward slope of the mountains on the south are interpreted as inward-facing escarpments that have been eroded in the limestone overlying the basalt. The mountains south of the trough rise steeply to an altitude of about 700 meters above sea level and are deeply dissected by V-shaped ravines.

From Miragoâne westward to Baie des Baradères the coast is bordered by an emerged terrace, back of which is an irregular mountain mass. From

Miragoâne to Anse-à-Veau these mountains apparently are composed of limestone. They rise to a maximum altitude of about 800 meters above sea level. From Anse-à-Veau to the valley of Rivière des Baradères the mountains are composed of limestone and basalt and other volcanic rocks. Along the south coast of Baradères Bay mountain ridges extend down to the coast. The mountain crests that are composed of limestone rise in sharp peaks and cliffs above the more gentle slopes that have been eroded on volcanic rocks.

INTERIOR.

East of the gap traversed by the road from Miragoâne to Aquin the interior of the eastern part of the massif consists of mountain ranges rising to a maximum altitude of perhaps 1,500 meters above sea level. South of Grand-Goave the highest peak has an altitude of 1,340 meters above sea level. South of Petit-Goave and Miragoâne the crest of the mountains lies in the central part of the peninsula, but farther west it is close to the south coast.

North of the crest the road from Miragoâne to Aquin follows a narrow depression about 15 kilometers long, called the Fond-des-Nègres, the central part of which has an altitude of about 260 meters above sea level. The depression trends almost westward, parallel to the trend of the structural features, and in general it closely resembles the trough south of Tapion de Miragoâne. It probably represents the eroded crest of an anticline and has inward-facing escarpments of limestone. The basaltic rocks in the floor of the depression are largely concealed by alluvium. Between Fond-des-Nègres and the Aquin Plain the road follows the lowest gap (altitude 300 meters) in the crest of the Southern Peninsula. The Colline Valley is a narrow depression in the mountains east of the gap. As seen from a distance it resembles the Fond-des-Nègres.

Asile Valley.

The Asile Valley is an interior lowland surrounded by rugged mountains. It probably is partly outlined by faults. The valley trends westward, parallel to the main structural features. The valley is at least 12 kilometers long and 3 kilometers wide. Its western and central parts are drained by Rivière des Pins, which flows eastward to l'Asile and is joined by the westward-flowing Rivière Serpent, which drains the eastern part. The two streams form the Grande Rivière des Nippes, which flows northward through the mountains in a deep gorge. The floor of the valley slopes from an altitude of 250 or 300 meters near the western end to an altitude of about 125 meters above sea level at l'Asile. Poorly consolidated and gently folded detrital rocks of Miocene age underlie the valley.

The lower eastern part of the valley is a rolling lowland that has a maximum relief of 50 meters. The hills, which generally consist of rather hard beds, are smooth and rounded but are truncated by bluffs, 5 to 15 meters

high, along the streams. The higher western part is a plateau underlain by coarse, poorly consolidated conglomerate and is deeply trenched by stream channels along which bluff or talus slopes reach a height of 100 meters. This relief is the result of an increasingly greater depth of erosion to the west. The western border of the plateau appears to abut against the high ranges of the Montagnes de la Hotte.

The rugged mountains on the south side of the valley rise steeply to an estimated altitude of 800 meters above sea level. The trail from l'Asile to Cavaillon crosses their crest at an altitude of 500 meters above sea level. The trail from Aquin to l'Asile follows a lower pass that has an altitude of 300 meters above sea level. Rivière Serpent enters the valley through a gorge on the east. The mountains on the north side of the valley are not so rugged as those on the south side. The trail from l'Asile to Anse-à-Veau crosses their crest at an altitude of 325 meters above sea level.

SOUTH SLOPE.

From Jacmel westward to Bainet the mountain ridges on the south slope of the massif trend southeastward toward the coast. The trail from Jacmel to Bainet crosses the crest of the first ridge at an altitude of 430 meters above sea level. Morne Laporte, southeast of the trail, rises about 50 meters higher. Along the trail the crest of the ridge is flat. Northeast of the crest there is a plateau that stands about 300 meters above sea level, the edge of which slopes down steeply to the alluvial plain at Jacmel. About 15 kilometers northwest of Morne Laporte the crest of the ridge attains an altitude of about 1,000 meters above sea level, but the trail from Grand-Goave to Bainet crosses the crest at an altitude of 720 meters above sea level. Near the coast a dissected plateau that has a gentle seaward slope borders this ridge. The inner edge of this coastal plateau has an altitude of about 100 meters above sea level, but isolated hills rise 50 meters higher. The seaward edge of the plateau is a degraded sea cliff, the foot of which has an altitude of 40 or 50 meters above sea level. The plateau probably represents a plain that was being base-leveled during the time when the sea cliff was cut. The base of the degraded sea cliff is the inner edge of an emerged coastal terrace that slopes seaward to a much fresher and more persistent sea cliff about 10 meters high, which is one of the most conspicuous features along the coast between Jacmel and Côtes-de-Fer. The base of this cliff has an altitude of 20 meters above sea level and forms the inner edge of a lower emerged coastal terrace. Both of these emerged terraces show clearly in a profile view of Cap Bainet, where they have a maximum width of 1 kilometer.

Between Mayette and Bainet a dissected plateau extends inland from the lower terrace for a distance of about 5 kilometers. The inner edge of the plateau has an estimated altitude of 75 to 100 meters above sea level and slopes seaward to an altitude of about 50 meters. It is separated from the mountains by an interior valley that strikes a little north of west.

The eastern part of the valley is drained by a gorge that cuts across the plateau north of Cap Raymond and the western part by a similar but smaller gorge about 5 kilometers east of Mayette.

Flat-topped hills near Côtes-de-Fer that have an altitude of 40 to 50 meters above sea level probably are isolated remnants of the upper emerged coastal terrace. Their crests slope seaward, and they are covered with a veneer of soft coralliferous limestone and imperfectly consolidated gravels. Deeply incised dry stream channels drain southward between the hills. Near Mayette the dissection is even greater.

Between Côtes-de-Fer and Flamands Bay the south slope of the mountains is separated from the shore by a coastal plain, the central part of which has a maximum width of 8 kilometers and is called the Lhomonde Plain. Near the shore this plain is about 8 meters above sea level and apparently corresponds to the seaward part of the prominent lower terrace east of Côtes-de-Fer. Dry stream channels are intrenched in flood plains 5 meters below the surface of the plain. Toward the interior the surface of the plain is more irregular and is broken by low hills, but whether there is an emerged sea cliff at the rear of the plain is not known.

Between Flamands Bay and the Aquin Plain low irregular hills composed of limestone of Eocene age extend down to the shore. They have a maximum altitude of 300 meters above sea level. From this locality westward to the Cayes Plain the surface features of the south slope of the massif are entirely different. The crest of the peninsula approaches the south slope and the rugged mountains extend almost or quite to the shore line. At the eastern extremity of this region the alluvial Aquin Plain separates the mountains from the shore. Small streams are intrenched several meters in the alluvial gravels and silt on the plain. South of Vieux-Bourg d'Aquin a low hill rises above the surface of the plain.

From the Aquin Plain westward to the Cayes Plain the rugged mountains south of the Asile Valley extend down to the shore line. Spurs along the coast have an altitude of 150 to 200 meters above sea level. The crests of the mountains and of the spurs along the coast generally are composed of limestone, but basaltic volcanic rocks, which underlie the limestone, are exposed on the lower slopes of the mountains and in the valleys. The slopes cut in limestone are steeper and more rugged than those cut in the volcanic rocks and at many localities are scarred by cliffs. Rivière de St.-Louis flows through a deep gap in the coastal range.

Western Part.

NORTH SLOPE.

The north slope of the western part is mountainous, but most of the peaks have an altitude of less than 800 meters above sea level. The mountains generally trend a little north of west or north of east. They are

composed principally of limestone of Eocene age. The slopes are steep and are in many places broken by cliffs, and most of the valleys are deep and narrow, but this region is not so inaccessible as the Montagnes de la Hotte. Near Corail and Pestel large areas of karst topography contain sink holes of enormous size. The limestone in these areas yields on weathering red clay, which is protected from surface erosion, as the drainage is underground, and forms smooth, flat uplands, gentle slopes and level sink-hole fillings, thus modifying the relief that characterizes most regions in the Republic where limestone is the surface rock.

Several small interior lowlands resemble on a reduced scale the Asile Valley. The largest on the north slope is on the Grande Rivière de Jérémie. This lowland is about 3 kilometers wide and at least 7 or 8 kilometers long, but its eastern boundary is not known. It is underlain by folded marl and firmly consolidated conglomerate of Miocene age. The marl crops out in rolling rounded hills, but the conglomerate forms distinct eastward-trending ridges. The river is intrenched about 10 meters below the surface of the lowland in a flood plain that has a maximum width of 1 kilometer. A similar but smaller interior lowland is on the Bras-à-Droit de la Grande Rivière de Jérémie below Chambellan. It is less than 4 kilometers long and 2 kilometers wide. Another interior lowland that may be the eastward prolongation of the one on the Grande Rivière de Jérémie probably lies south of Les Roseaux.

INTERIOR; MONTAGNES DE LA HOTTE.

The name Montagnes de la Hotte is here used to include several high mountain ranges in the interior of the western part of the massif and on the south slope west of the Port-Salut Peninsula. The high range immediately north of Tiburon Bay and the valley of Rivière de Tiburon is called the Montagne de Tiburon, but most of the ranges are unnamed.

The Montagnes de la Hotte generally consist of at least three parallel ranges trending almost westward. They are the highest ranges in the massif. The central range is apparently the highest. Only the southern, western, and northern margins of these ranges were examined. Mont la Hotte, the highest peak, stands about 2,000 meters above sea level.[1] Little is known of the surface features of the central ranges. These mountains must be very rugged, as no trails that can be used by pack animals cross this part of the massif, and they are rarely crossed even on foot. The ranges on the south slope rise abruptly to altitudes of about 1,000 meters above sea level within a short distance from the coast.

The ranges on the south slope and the central ranges along the west coast consist principally of basaltic volcanic rocks and overlying Eocene limestone. Large areas in the interior ranges apparently consist of older

[1] On the Thomasset map the altitude of this peak is shown as 2,255 meters. The altitudes shown on this map for other points are too great.

rocks. At many localities the crests of the ranges consist of limestone and the lower slopes of basalt. Here as in other regions the limestone slopes are very steep and rugged, and dip slopes terminate in abrupt escarpments. The foothills that consist of basalt are generally less rugged.

The Camp Perrin Valley, in the eastern part of the Montagnes de la Hotte, is an interior lowland similar to those on the north slope and to the Asile Valley. It is perhaps 20 kilometers long and has a maximum width of 3 kilometers. It is floored with Miocene rocks, like the other interior lowlands.

SOUTH SLOPE.

Cayes Plain.

The Cayes Plain is the only large coastal plain in the Southern Peninsula west of the Léogane Plain. It extends northwestward from Cayes Bay for a distance of 20 kilometers and has a width of 15 to 20 kilometers. The plain is covered with alluvium. At its northwest extremity the altitude of the plain is about 100 meters above sea level, and the surface slopes gently southeastward to the sea. In the northern part small isolated hills consisting of limestone of Miocene age rise above the plain. The slopes of the hills are steep, but their crests usually are rounded. The gently sloping surface of the plain is trenched by several rivers, which flow southeastward. Near the mountains at the head of the plain the trenching reaches a depth of 10 to 15 meters, but near the coast it is only 2 to 5 meters.

Port-Salut Peninsula.

The Port-Salut Peninsula extends southeastward from the foot of the Montagnes de la Hotte west of the Cayes Plain and Cayes Bay. The name is derived from that of the largest town on the peninsula, Port-Salut. The peninsula is about 20 kilometers long and 10 to 12 kilometers wide. The surface rocks in the central part of the peninsula are thin-bedded limestones of Eocene age. This limestone is fringed by younger coralliferous limestone.

The interior of the peninsula is a strongly dissected plateau. Many rounded hills of accordant height indicate that the surface of the plateau stood about 300 meters above sea level. The relief is about 100 meters. The valleys between the hills have smoothly curving sides. The rounded hills and open valleys of the peninsula are strongly contrasted to the steep, rugged slopes and deep V-shaped valleys in the Montagnes de la Hotte, where part of the Eocene limestone is massive. The slope from the eastern edge of the plateau facing the Cayes Plain is very abrupt and is deeply furrowed by narrow ravines. This steep plateau face probably is an eroded fault scarp.

Coralliferous limestone of Quaternary age extends around the coast of the peninsula and covers several emerged coastal terraces, which slope

seaward and are backed by emerged sea cliffs. At Anse à Juif, on the west coast, emerged terraces were seen at altitudes of 20, 40, and 50 meters above sea level. Near Port-Salut the lowest terrace stands at an altitude of 10 meters above sea level and the next higher one at an altitude of 20 meters. At some localities the coralliferous limestone extends up to an altitude of about 100 meters above sea level, but the highest terraces are not so well preserved as the lower ones.

Drainage.

The crest of the peninsula is the main divide from which streams flow into Gonave Gulf to the north and into the Caribbean Sea to the south. Between Jacmel and Aquin the south slope is poorly watered and has few through-flowing streams. Some of the streams are adjusted to the structure. Rivière des Pins flows eastward along the strike of the rocks and Rivière Serpent westward. Rivière de Cavaillon, which is the largest stream on the south slope of the massif, drains a long, narrow interior valley that trends southeastward and finally escapes southward through a series of narrow gorges across the coastal ranges. At the western end of the peninsula Rivière Tiburon and other smaller streams flow westward in courses that are approximately parallel to the structural trend. Grande Rivière de Jérémie flows northeastward for a long distance in a strike valley underlain partly by Eocene limestone and partly by the Miocene beds of the interior lowland. The stream pierces the high ridges of Eocene limestone on the north side of the lowland in narrow, steep-walled gaps.

Shore Features.

The littoral and sublittoral features of the different parts of the Massif de la Hotte are related to the surface features of the interior, but for convenience they are described in order from Grand-Goave westward around the extremity of the peninsula and then eastward along the south coast to Jacmel.

North coast.

The steep northward slopes of Tapion du Petit-Goave and Tapion de Miragoâne are truncated along the shore line by bold sea cliffs. Petit-Goave Bay may be interpreted as a submerged valley that has been partly filled. The irregular reentrants on the east side of Miragoâne Bay, which are separated by cliffed promontories, indicate slight submergence.

A shore of emergence extends from Miragoâne westward to Baradères Bay. The shore line is straight and is bordered by a nearly continuous sea cliff, which is at most places less than 10 meters high. This sea cliff is the seaward face of an emerged terrace covered with coralliferous limestone of Quaternary age. The maximum altitude of the terrace near Anse-à-Veau is 15 to 20 meters above sea level, and its width is 1 to 2

kilometers. The altitude of the terrace gradually decreases westward and more rapidly eastward. At Petit-Trou de Nippes, near Baradères Bay, it drops down to sea level. Along the west side of Miragoâne Bay the terrace is represented by the mud flats and mangrove thickets that lie in front of abandoned sea cliffs. The few streams that cut across the terrace are incised to sea level. The channel of the tidal stream at Anse-à-Veau is very narrow.

Between Petit-Trou de Nippes and Corail the shore line is very irregular. Baradères Bay and Cayemites Bay, two extensive bodies of water, are partly inclosed by the Bec du Marsouin Peninsula and the island Grande Cayemite. The shore line on the south sides of Baradères Bay and Cayemites Bay is bordered by short, high cliffs that truncate steep slopes of limestone of Eocene age. As wave cutting is not very effective in these sheltered bays, it seems that the cliffs may be due to the undermining and solution of limestone along the underground streams that emerge as springs on the shore. The exposed parts of the Bec du Marsouin Peninsula and Grande Cayemite are truncated by sea cliffs about 10 meters high. An emerged terrace that has the same altitude as the terrace east of Petit-Trou de Nippes borders the northeastern extremity of the peninsula and probably extends along the north coast of the peninsula and of Grande Cayemite. The shore features in this region may be due to the submergence of an area of karst topography followed by emergence of the northern part similar to the emergence of the shore from Petit-Trou de Nippes eastward to Miragoâne.

Between Corail and Jérémie the coast is low and is bordered by a narrow fringe of alluvium. Discontinuous remnants of a narrow terrace veneered with coralliferous limestone of Quaternary age extend from Les Roseaux to Jérémie. At Les Roseaux the outer edge of the terrace is less than 5 meters above sea level. At Jérémie the Quaternary limestone does not form a well-defined terrace but extends as irregular patches up to altitudes of at least 25 meters above sea level.

Similar remnants of recently emerged Quaternary limestone probably extend westward from Jérémie, but the coast rapidly takes on the features of the west coast, and cliffed promontories that are separated by bay head beaches become prominent.

WEST COAST.

The west coast of the Southern Peninsula is extraordinarily rugged, particularly from Les Irois to Tiburon. Spurs extending to the shore line are truncated by bold cliffs that have a maximum height of 100 meters. Between the cliffed promontories are small bays with bay-head beaches. Some of the bay-head beaches—for example, the one south of Anse-d'Hainault—inclose small marshes. This rugged coast is interrupted at Tiburon by a narrow alluvial plain bordered by a gravel beach that obstructs the discharge of the small flow of Rivière Tiburon.

SOUTH COAST.

East of Anse du Milieu the shore abruptly takes on features indicating emergence. A low hill at Pointe des Aigrettes, which has an altitude of about 15 meters above sea level, is capped by limestone, probably of Quaternary age, such as is common along the coast east of Les Anglais. A low emerged beach composed of sand and gravel is a conspicuous shore feature between Anse du Milieu and La Cahouane. The altitude of the beach is 3 to 4 meters above sea level, and it is backed by a low terrace composed of beach gravel, which at some places slopes toward the foot of the mountains. The width of the terrace is 1 to 2 kilometers. At its western end a tidal inlet leads into an area of salt marshes and mangrove thickets.

The coast between La Cahouane and Les Anglais resembles the coast north of Tiburon, as cliffed promontories that are not veneered with Quaternary limestone are the most conspicuous shore features.

The coast between Les Anglais and Anse à Juif has a general northwesterly trend, diagonal to that of the structural trend, as is shown by the many small segments that trend almost eastward, so that the shore consists of many right-angled turns. These segments are the terminations of mountain ranges that rise steeply to altitudes of 700 meters or more above sea level. The ruggedness of the coast is generally modified by a narrow fringe of low foothills or by distinct terraces veneered with Quaternary limestone that probably extends up to an altitude of 100 meters above sea level. The highest terraces can hardly be distinguished. On the north side of Anse à Drick there is a distinct terrace that has an average width of 50 meters and an altitude of 20 meters above sea level. At the landward side of the terrace there is a sea cliff about 10 meters high, above which probably rises another terrace, although the slope is rather steep. At the shore line the terraces are truncated by sea cliffs 10 to 30 meters high. Many small streams from the mountains cut across the terraced coast, and the remnants of the terraces are separated by small alluvial plains. Sandy beaches and bars obstruct the mouths of the streams at the seaward margin of these plains. At several localities an emerged beach 2 or 3 meters above sea level, similar to the emerged beach west of La Cahouane, is conspicuous.

The entire shore of the Port-Salut Peninsula is straighter and more uniform than the shore to the west, and the features of a shore of emergence are more continuous. The emerged coastal terraces in this region are described on p. 413. The lowest terrace has a seaward sea cliff 2 to 8 meters high. The mouths of most of the streams that are intrenched in the terraces are closed by bars, and the water discharges beneath the surface. On the west side of the peninsula the bars apparently are built by currents moving southward. Some of the streams flow a considerable distance parallel to the beach inside the bar before finding an outlet.

The shore of the Cayes Plain is straight except for the small indentations at the mouths of the many small streams that enter the bay. The

alluvium that covers the plain is usually truncated at the shore line by cliffs 1 or 2 meters high. The plain is being extended seaward on the shallow platform embracing Cayes Bay and Ile-à-Vache. This coast lies between a shore line of emergence on the southwest and a shore line of submergence on the northeast.

The features of the shore line from the northern border of the Cayes Plain eastward to Aquin indicate submergence. Its outline is very irregular and includes many deep bays with bayhead beaches. The bays are separated by cliffed promontories, along the sides of which there are bayside beaches and mangrove thickets between short, high sea cliffs.

From the east side of Aquin Bay eastward to Jacmel the shore line is relatively straight and the features indicate emergence. The coastal plain that extends eastward to Côtes-de-Fer is bordered by low sea cliffs or by beaches that lie in front of an eroded low sea cliff. Between Côtes-de-Fer and Jacmel stretches an almost continuous sea cliff that has a height of about 15 meters. (See pp. 409-410.) Bainet Bay, a structural depression, indents the coast.

SUBLITTORAL FEATURES.

NORTH COAST.

Between Grand-Goave and Miragoâne the width of the sublittoral platform, as limited by the 20-fathom line, is less than 1 kilometer, except at Petit-Goave Bay and Miragoâne Bay. Neither of these bays lies in a plunging syncline, as do so many bays in the Republic, a fact shown by the outline of the 20-fathom line. At Petit-Goave Bay the 20-fathom line extends directly across the entrance, and at Miragoâne Bay it is only slightly indented. The features of the two bays support the conclusion that the littoral and sublittoral features are due to slight submergence, although the soundings are not extensive enough to substantiate the conclusion.

Between Miragoâne Bay and Baradères Bay the sublittoral platform is extremely narrow, as would be expected on a shore of emergence.

The sublittoral platform embraces the extensive bodies of water that are called Baradères Bay and Cayemites Bay. The 20-fathom line is indented at the east end of both bays, but the platform on the outer sides of Bec du Marsouin Peninsula and Grande Cayemite is very narrow. The outer margin has the features of a shore of emergence, but apparently the bays owe their outline to earlier submergence. Westward from the west end of Cayemites Bay the sublittoral platform along the north coast is very narrow, but it gradually widens.

West Coast.

An extensive triangular sublittoral platform extends westward from the west coast between Cap Dame-Marie and Cap Tiburon. The apex of the platform is 24 kilometers west of Cap des Irois, the western extremity on

the coast. Figure 25, *A*, a profile of this platform, shows that on this exposed coast the maximum depth of effective wave erosion is only 15 fathoms. This wide abrasion platform indicates that the adjacent coast has stood still for a long time or has very slowly subsided. The littoral and sublittoral features of the Southern Peninsula are entirely different from those of the Northwest Peninsula and indicate a correspondingly different geologic history.

South Coast.

Between Cap Tiburon and the southeast end of the Port-Salut Peninsula the 20-fathom line parallels the shore and embraces a narrow sublittoral platform. A curious bilobed indentation of deeper water extends into the platform on the south side of the Port-Salut Peninsula. Along the south

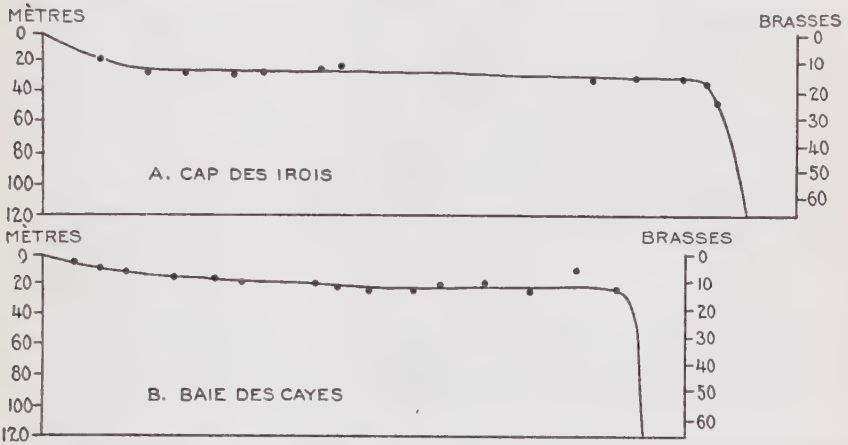


Figure 25.—Subaqueous profiles off the west and south coasts of the Southern Peninsula.

Horizontal scale 1 : 250,000; vertical scale exaggerated 50 times.

side of this peninsula the offshore slope from the edge of the platform is very steep. A depth of 1,900 fathoms (3,475 meters) is recorded 12 kilometers south of the southwest end of the peninsula.

An extensive sublittoral platform extends from the southeast end of the Port-Salut Peninsula and embraces Cayes Bay and Ile-à-Vache. Figure 25, *B*, is a profile of this platform drawn southeastward from l'Acul. The depth of water on the platform is less than 15 fathoms (27 meters) except in the channel north of Ile-à-Vache, where it is a little more than 20 fathoms (36 meters). A ridge extends southeastward from Les Cayes to Ile à Vache and along the north side of that island. Along this ridge numerous reefs lie awash and small cays rise above the surface of the water. The channel on the north side of this ridge probably is a submerged stream channel extending out from Cavaillon Bay. The littoral and sublittoral features of the coast from Les Cayes eastward to Aquin

indicate submergence. The slope from the outer edge of the platform is very steep. A depth of 2,130 fathoms (3,895 meters) is recorded 12 kilometers southeast of the southeast end of Ile à Vache.

From Aquin Bay eastward to Côtes-de-Fer the sublittoral platforms decrease in width. The outline of the 20-fathom line is more irregular than the shore line. East of Côtes-de-Fer the platform is narrow, and its outer edge closely parallels the shore line. At Bainet Bay the 20-fathom line is deeply indented parallel to the indentation of the shore line.

GONAVE ISLAND.

GENERAL RELATIONS.

Gonave Island is the largest outlying island embraced by the Republic of Haiti. It has a length of 57 kilometers and a maximum width of 15 kilometers. The axis of the island extends from northwest to southeast, almost paralleling the shore and the structural features of the mainland from Cap St.-Marc southeastward to the Cul-de-Sac Plain. The average width of the channel on the northeast side of the island, St.-Marc Canal, is 20 kilometers. The width of Gonave Canal, on the south side, increases from 27 kilometers at the southeast end of the island to 44 kilometers at the northwest end.

LAND FEATURES.

Structurally the island is an asymmetric anticline, the crest of which plunges both northwestward and southeastward. Some of the most striking surface features are due to the solution of limestone, which is the only surface rock on the island. The island may be divided into two almost equal parts, having different kinds of surface features. The southeast half is more rugged and has a greater variety of surface features than the northwest half.

Southeast Half.

The southeast half of the island contains a ridge along the south coast, an interior dissected plateau at an altitude of 300 to 500 meters above sea level, and a dissected plateau along the north coast extending from sea level to an altitude of 300 to 400 meters above sea level.

RIDGE ALONG SOUTH COAST.

A high ridge near the south coast, extending from the longitude of Picmi to a locality northwest of Pointe à Raquette, is the most conspicuous surface feature of the southeastern half of the island. This ridge coincides with the crest of the Gonave Island anticline. The eastern part of the ridge is narrower than the western part. Along its entire length the crest is flat and several hundred meters wide. The central part of the ridge is more eroded than the extremities. The highest knobs on the crest of the

ridge are Morne Chien Content at the east end and Morne la Pierre at the west end, both of which have an altitude of about 755 meters above sea level and rise about 100 meters above the lowest part of the crest of the ridge. The south slope of the ridge is steeper than the north slope, corresponding to the steeper south limb of the anticline, and is scarred by cliffs. The south slope extends down to the shore line, but the north slope is bounded by the dissected plateau described on page 420.

Southeast of Morne Chien Content the ridge is interrupted by a broad saddle called Fond-l'Aurore, which extends from Picmi northeastward across the island toward Trou à l'Eau. Southeast of the saddle the ridge is much lower but apparently is composed of the same rocks. The region that includes the highest part of the ridge southeast of the saddle is called Fond-Plaisir, and the highest knob in this region has an altitude of about 460 meters above sea level.

MAPOUX PLAIN.

The Mapoux Plain is a remarkable inclosed depression on the north slope of the ridge northeast of Morne la Pierre. It is about 5 kilometers long and about 1 kilometer wide, and it trends N. 70° W. It is completely encircled by ridges of limestone. The main trails enter the plain at the east and west ends, where the limestone wall is lowest. Plate XXXII, *B*, shows part of the ridge along the north side of the plain. The crest of this ridge is very jagged, and its slope is scarred by cliffs. The crest of the ridge on the south side, although higher than the ridge on the north, is more even, and its slope into the plain is more gentle and uniform.

The features of the ridges encircling the plain indicate that the depression owes its origin to the enlargement of solution channels down the dip along bedding planes and the subsequent deepening of the channels by the solution of underlying beds. The smooth, relatively gentle northward slope of the ridge on the south side of the plain corresponds to the northward dip of the rocks. The jagged southward slope of the ridge on the north side is due to the undermining of overhanging ledges of limestone. The open-textured limestone in which the plain has been etched overlies more impervious chalky limestone, which controls the floor of the depression, although in the plain itself the chalky limestone is concealed by residual clay and soil. Continued widening of the plain by undermining of the ridge on the north side is indicated by the blocks of limestone that have tumbled down from overhanging ledges and are strewn along the foot of the ridge. If the open-textured Eocene limestone in which the plain is etched has been exposed to weathering since its emergence at the end of Eocene time it seems reasonable to believe that most of it would have been removed and that the underlying less pervious chalky limestone would now be the surface rock in this part of the island. It is inferred that the open-textured limestone was long protected by a cover of Miocene lime-

stone that has been entirely removed. Depressions similar to the Mapoux Plain are striking features of the limestone plateau of the island of Jamaica.[1]

INTERIOR DISSECTED PLATEAU.

A strongly dissected plateau that has an altitude of 300 to 500 meters above sea level extends along the north side and west end of the high ridge that parallels the south coast. The area of this plateau approximately coincides with the outcrop of chalky limestone of Eocene age, which underlies the open-textured limestone that forms the ridge along the south coast. On the north side of the ridge the plateau slopes northward, and if its surface were restored the slope would closely correspond to the northward dip of the rocks. At the west end of the plateau the surface slopes northwestward along the plunging crest and more steeply southward along the steep south limb of the anticline. On the north side of the coastal ridge the plateau is deeply dissected by ravines that extend back to the coastal ridge. The interstream areas are wide and rolling.

The trail from Grande Ravine to Fond-Nègre crosses the western part of this plateau. Near its west end small isolated outliers of limestone rise abruptly from the surface. Some of these outliers are strikingly similar to ruined walls. They are remnants of a formerly more extensive cover of Miocene limestone, most of which has been removed, principally by solution. Similar isolated patches of limestone are characteristic features of the limestone plateau of Jamaica[2] and of the plain along the north coast of Porto Rico, where they are called haystack or pepino hills.[3]

DISSECTED PLATEAU ALONG NORTH COAST.

A dissected plateau extends back from the north coast to an altitude of 300 to 400 meters above sea level. The surface of this plateau approximately coincides with the outcrop of Miocene limestone. The inland part of the plateau slopes seaward at a rate that corresponds to the seaward dip of the rocks, but near the coast the slope is more abrupt. The plateau is dissected by ravines that head back in the higher interior plateau or in the ridge along the south coast. On this plateau outcrops of bedrock are much more common than on the interior plateau.

Fond-l'Aurore, the broad saddle extending across the island northeast of Picmi, is part of this plateau. The crest of the saddle has an altitude of about 340 meters above sea level. East of Fond-l'Aurore the plateau surface is hardly recognizable on account of the steep seaward slope.

[1] Hill, R. T., The geology and physical geography of Jamaica: Mus. Comp. Zool. Harvard College Bull., vol. 34, pp. 26-30, 1899.

[2] Hill, R. T., op. cit., pp. 25-26.

[3] Berkey, C. P., Geological reconnaissance of Porto Rico: New York Acad. Sci. Ann., vol. 26, pp. 51-53, 1915.

Northwest Half.

The northwest half of the island comprises only the northwestward extension of the plateau along the north coast of the southeast half. This plateau widens in the northwest half and embraces the entire width of the island except a narrow strip of mud flats along the coasts. Limestone of Miocene age is the surface rock in the entire northwest half of the island, as in the coastal plateau of the southeast half, and the surface features of the two regions are similar. The drainage channels are poorly defined, and the relief is largely the result of solution of the limestone.

The eastern part is low and has little relief, but the western part is more rugged. In the eastern part of the region called Grande Vide there are low, irregularly trending ridges that have a maximum altitude of about 300 meters above sea level. In the western part of Grande Vide the surface of the plateau has an altitude of 310 meters above sea level. A low rounded knob, the highest point in this part of the island, attains an altitude of 320 meters above sea level. Between Grande Vide and the northwest end of the island the plateau surface is lower, but along the coast at the northwest end a low ridge rises above the plateau.

Drainage.

There are no through-flowing streams on the entire island. The small flows of water that seep out in the deep ravine northeast of Picmi and in the ravine southwest of Anse-à-Galet rapidly disappear.

In the southeast half of the island the main divide is at most places the crest of the high ridge along the south coast. Relatively long northward-draining ravines head in this ridge and extend across the interior plateau and the coastal plateau to the sea. The shorter southward-draining ravines have a much steeper gradient. East of Morne Chien Content one of the southward-draining ravines has pierced the crest of the ridge and captured part of the drainage on the north slope. The deep ravine northwest of Picmi heads in the saddle called Fond-l'Aurore, where the divide swings far northward.

Shore Features.

At the northwest end of the island high cliffs truncate the ridge along the coast. Along the north and south coasts of the northwest half the limestone plateau is bordered by mud flats, which at many localities embrace mangrove thickets. The mud flats continue along the north coast of the island as far as a locality between Etroit and Anse-à-Galets, where the limestone plateau extends down to the shore. Near Anse-à-Galets there is a similar mud flat. The mud flats apparently are the result of the filling in of inlets behind offshore bars, and the lagoons on the north coast, such as Grande Lagune and Chérissable Lagune, are isolated remnants of inlets. Plate VI, *C* (p. 64) is a view of Chérissable Lagune

showing the mud flat on the landward side and the mangrove thicket on the seaward side.

West of Picmi the steep slope of the coastal ridge is truncated by sea cliffs. Near Picmi there is a mud flat similar to the flats on the north and south coasts farther west.

Along the south shore of the east end of the island promontories truncated by sea cliffs are separated by shallow indentations that have bayhead beaches. The peninsula at the southeast extremity of the island may be an island tied to the main island. This interpretation would account for Grande Baie and Baie du Parc and the inclosed body of water in the isthmus that joins the peninsula to the main island. This part of the island was seen only from a distance.

SUBLITTORAL FEATURES.

A narrow sublittoral platform encircles the island. The platform is slightly wider along the south coast than along the north coast. At its southeast end it widens and forms the apex of the extensive V-shaped platform enclosing the depression in the seaward prolongation of the Cul-de-Sac Plain, described on pages 397-398.

An inspection of the chart would suggest recent emergence of the island, for in other parts of the Republic such narrow and shallow sublittoral platforms are associated with shore lines of emergence. The littoral features, however, indicate that the shore line has stood still for a relatively long time. The platform probably was not very wide at any time. As the island lies in the deep gulf between the Northwest and the Southern Peninsula it is protected from the waves of the open ocean, and the effectiveness of wave attack is thus reduced. On the north coast west of Anse-à-Galets and on the south coast west of La Mahoterie the platform was probably once wider than it is now, its width having been reduced by filling behind offshore bars, as outlined on page 421. The small islands on the outer edge of the platform east of Etroit on the north coast probably are offshore bars covered with mangrove thickets and represent an early stage in the building of the mud flats and inclosed lagoons.

Part IV. MINERAL RESOURCES.

By Wilbur S. Burbank, John S. Brown, and Wendell P. Woodring.

METALS.

INTRODUCTION AND SUMMARY BY METALS.

Extent of examination.—Only the mineral deposits that were examined during the reconnaissance are here described. For lack of time or lack of ready accessibility many reported mineral deposits could not be examined, and some reports and rumors to which attention was given proved to be without foundation. Many of these reports were made by country people or were based on their observations. To them any unusual or striking mineral occurrence may be called a "mine," and, unfortunately, the frequency of such reports tends to discourage their careful consideration by competent investigators.

No mining is now in progress in the country, and although there are numerous prospects, none of them were being worked at the time of this reconnaissance, owing either to lack of capital or to lack of commercial quantities of ore. It is quite possible that the country may contain valuable mineral deposits and that such deposits may be discovered by intelligent exploration. Moreover, many of the known low-grade deposits that are now valueless may become valuable through the general economic development of the country, improvements in methods of ore extraction and treatment, or enhancement in the value of metals, or a combination of these factors.

Iron.—No iron deposits of commercial value are known. Deposits of magnetic iron ore near Limonade were examined, but the quantity of iron in them is small. (See pp. 468-470.) Some iron is found in contact-metamorphic copper deposits in limestone in the Terre-Neuve district. (See pp. 438, 447). Residual iron deposits are reported to occur at a number of places in the western part of the Southern Peninsula. Those at Anse d'Hainault and in Section Plymouth were visited. (See pp. 479-480.) These deposits are of low grade and have no commercial value. Residual concretionary masses of iron and manganese minerals were noted on igneous rocks at several places in the northern part of the Republic. The deposits are very thin and are of low grade.

Copper.—Copper deposits are found at several places, the most valuable being the contact-metamorphic deposits and veins of the Terre-Neuve district. (See pp. 425-459.) Although these deposits are not now being

mined, they have been considerably prospected and some ore has been shipped from them to New York. Copper-bearing veins are found at many other places in the northern part of the Republic, but few if any of them contain sufficient copper to be profitably mined. (See pp. 459-468.) The deposits at Grande-Rivière du Nord have received considerable attention from prospectors. Traces of copper have been reported from the areas of basaltic rock in the Southern Peninsula, some of them in the Commune of Anse d'Hainault, but none of these areas was visited.

Manganese.—During the reconnaissance deposits of manganese ore were discovered in the Commune of Gros-Morne. (See p. 470.) These deposits have not been prospected, nor have they ever before been reported. The known ore is not of commercial grade in the present manganese market. Manganese is also said to occur at several places in the Commune of Jacmel, but only one small deposit was examined during the reconnaissance. (See p. 475.) Negligible amounts of manganese and iron form residual concretions on igneous rocks at several places in the northern part of the Republic. (See pp. 477-478.)

Lead and zinc.—No commercial deposits of lead and zinc are known, although some zinc blende and some galena are found in the copper veins at Terre-Neuve. Veins near Grande-Rivière du Nord are also reported to contain some galena. (See pp. 453, 460.)

Silver.—Silver is found in many of the copper veins of the Republic, but usually in small quantities. Some small enriched copper veins in the Terre-Neuve district contain a considerable proportion of silver. A small amount of silver is found also in the veins at Grande-Rivière du Nord.

Gold.—No deposits have been much exploited for gold, although the quartz veins at some places in the northern part of the Republic are said to contain native gold. (See p. 460.) Assays of ore taken from the copper deposits at Terre-Neuve yielded small quantities of gold, and traces of gold are found in most of the copper veins of the Republic. Gold is reported to occur in the sands of some of the rivers, such as the Grande Rivière du Nord, and in rivers in the vicinity of Limonade and near Plaisance, in the north, and Rivière Gosseline, in the south. Such occurrences were not confirmed, although traces of gold may probably be found in some of the northern streams.

Platinum.—Platinum and iridosmium are reported to occur in some quartz veins in the northern part of the country, but the report has apparently not been confirmed, nor has an attempt been made to exploit the deposits. Time was not available for visiting the localities or confirming these reports. (See pp. 460, 467.)

Mercury.—Native mercury is reported to have been found in the vicinity of Môle St.-Nicolas.[1] The geology of the region around Môle St.-Nicolas does not encourage a search for the source of the mercury, even

[1] Moreau de St. Méry, vol. 1, p. 104. Ferguson, E. G. W., The mineral resources of Haiti, West Indies: Mining World, vol. 31, pp. 133-135, 1909.

if its occurrence was natural. Cinnabar is reported to have been found at several places in the Republic, but detailed and accurate accounts are not available.

Chrome.—There is said to be a small deposit of sand containing chromite in the central part of Ile-à-Vache, off the southern coast near Les Cayes. This island was not visited. Analyses of chromite from this deposit have been published in French technical journals.[1]

MINERAL DEPOSITS OF THE TERRE-NEUVE DISTRICT.

By Wilbur S. Burbank and John S. Brown.

Introduction.

The mineral deposits and geology of the Terre-Neuve district were examined during a two weeks' reconnaissance in January, 1921. The conclusions recorded are based on this field work supplemented by a laboratory study of the minerals and rocks. Previously published accounts of the geology are meager and were found to be inaccurate in important details.

Location and Access.

The Terre-Neuve district is in the central part of the Montagnes de Terre-Neuve, in the Communes of Terre-Neuve and Gros-Morne. Its name is derived from its principal town, Terre-Neuve, which lies about 22 kilometers in a straight line northwest of Gonaïves. The location of the district with reference to other places and the main trails giving access to it are shown in Figure 26.

The principal mineral deposits are in an area about 10 kilometers long and 3 kilometers wide, which extends southeastward from Terre-Neuve. The mineralized area lies in the drainage basins of Rivière Colombier, which flows northwestward past Terre-Neuve, and of Rivière Bassin, which flows southeastward past Memé and Bassin. In this report the mineralized area drained by Rivière Colombier is called the Terre-Neuve Valley, and the area drained by Rivière Bassin is called the Memé Valley.

The mountain summits in the Terre-Neuve district rise 700 to 1,000 meters above sea level and the relief is 300 to 500 meters. The average trend of the mountain ranges and of the intervening valleys is about N. 50° W. The mountain slopes are steep and rugged, particularly in the areas underlain by limestone, where cliffs are common. (See pp. 367-368.)

Most of the drainage of the mineralized area is carried by Rivière Colombier and Rivière Bassin, which are small streams that probably reach the sea only during great floods. Underground drainage is developed at

[1] Berthier, M. P., Analyse de deux variétés de fer chromé; suivie d'une note sur les alliages du chrome avec le fer et avec l'acier: Annales des Mines, 1st sér., vol. 6, pp. 573-584, 1821. Boussingault, M., Sur la production, la constitution et les propriétés des aciers chromés: Annales de Chimie et de Physique, 5th sér., vol. 15, pp. 91-126, 1878. Translated in Jour. Iron and Steel Inst., no. 2, pp. 807-830, 1886.

some places in the limestone areas that surround the central part of the district and in these areas sink holes are common. Although Rivière Bassin near the head of Memé Valley is dry during part of the year there is a small, probably perennial flow of water for a kilometer or two below Memé. Moreover, some water for use in mining might be obtained either from shallow wells or shafts in the upper part of the valley. Such wells should be sunk near the beds of the deepest ravines.

Many of the crests of the ranges, particularly those southwest of Terre-Neuve, support hardly any vegetation except grass. The higher mountain

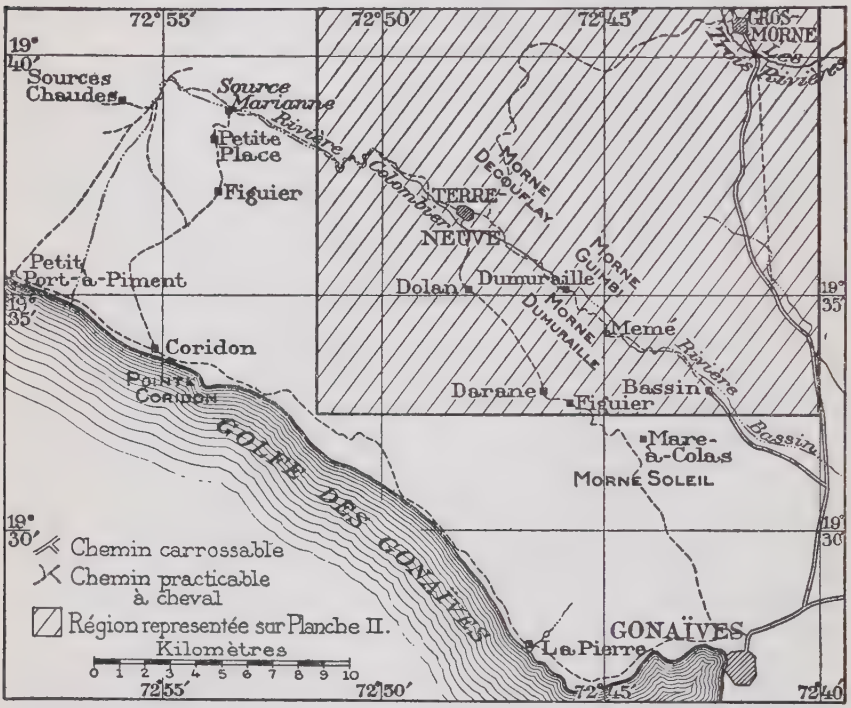


FIGURE 26.—Sketch map of the Terre-Neuve district showing the roads and principal trails. (After Tippenhauer.)

slopes in the Terre-Neuve and Memé valleys are generally covered with a thick growth of small brush. The valleys appear to benefit by the seepage of ground water and support more luxuriant vegetation and large trees. In the narrow valley of Rivière Colombier west of Terre-Neuve there is a thick stand of large trees. Thick growths of smaller trees were noted farther west along the same stream, near Source Marianne, and also in the southeast part of the district at Mare-à-Colas and between Memé and Bassin. (See Plate IV, *A*, p. 58, and p. 60.)

The seaward slopes and the eastern foothills of the Montagnes de Terre-Neuve receive little rain and are covered by stunted xerophytic vegetation.

At present the Terre-Neuve district can be reached only by foot or on horse-back. The principal trails are shown in Figure 26. Nearly all outside commerce and communication is carried on by way of Gonaïves. Two trails start from Gonaïves, one of which takes the shortest route by way of Morne Soleil to Darane, Dolan, and Terre-Neuve, traversing only a small part of the mineralized area. The distance between Gonaïves and Terre-Neuve along this trail is about 30 kilometers. The grades are steep, reaching 8 or 10 per cent in crossing Morne Soleil and in ascending from Mare-à-Colas to Darane. At one place the grade for several hundred meters is 15 per cent. The worst grades could be eliminated by realignment of the trail, but grades of 8 or 10 per cent or more at some places seem unavoidable, and for this reason the route can not easily be made practicable for vehicles. It is, however, a fair trail for pack animals. The part nearer Gonaïves was in good condition in 1921, and the whole length was then easily passable. This is the trail commonly used in traveling from Gonaïves to Terre-Neuve.

The other trail from Gonaïves to Terre-Neuve passes through Bassin and Memé and traverses a larger part of the mineralized zone. This trail branches from the road leading from Gonaïves to Gros-Morne at a locality about 10 kilometers from Gonaïves. Although unimproved, it is passable for vehicles and even for automobiles as far as Bassin. From Bassin to Memé the trail is good and could be made passable for vehicles without much difficulty. A railroad could easily be constructed as far as Bassin and perhaps even to Memé. From Memé to Terre-Neuve the grades are steep, as great or greater than those on the first trail, even though this route has been laid out with some care. Considerable recent work on this trail in 1921 has placed it in better condition than the other, but it is naturally more difficult to maintain. It is at least 35 kilometers long, somewhat longer than the trail first described. The trail first described is used preferably to reach Terre-Neuve; the other is used to reach localities in the Memé Valley from Gonaïves.

A trail leads westward from Terre-Neuve along the course of Rivière Colombier and reaches the sea at Port-à-Piment, a very small fishing habitation, and farther west at Anse Rouge, a small village. This trail is also used to reach the Sources Chaudes or Eaux Boynes. The distance from Terre-Neuve to Port-à-Piment, the nearest outlet to the sea, is about 30 kilometers, and to the Sources Chaudes, a little more than 20 kilometers. As this trail follows the river valley it has a fairly easy grade and is naturally good. It could be improved for vehicular traffic, and this route perhaps could be utilized by a railway, although very sharp curves would be unavoidable in the narrow canyon west of Terre-Neuve. Moreover, a railroad would probably be endangered occasionally by the floods that sweep down the narrow valley. Although this is the best trail into the Terre-Neuve valley, it is little used, because the region with which it

communicates is arid and very thinly settled and offers no facilities for commerce or communication with other parts of the Republic.

From Terre-Neuve an entirely unimproved and exceedingly difficult trail affords direct communication with Gros-Morne. This trail passes northeastward over Morne Découflay, down a deep valley in Section Moulin, and thence over a rolling lowland into Gros-Morne. Although one can ride a horse across Morne Découflay, most travelers prefer to walk at many places. The total distance from Terre-Neuve to Gros-Morne is about 20 kilometers.

Many trails, some passable on horseback and some only on foot, afford access to all the habitations in the district, but those described in the preceding paragraphs are the only practicable routes by which one can enter or leave the district. Several of the mining prospects in the Terre-Neuve Valley stand high on the mountain slopes and can be reached only by very poor trails, which at some places are passable only on foot.

Geology.

GENERAL FEATURES.

The oldest known rocks exposed in the Terre Neuve district consist of igneous rocks of different types, chiefly lavas, representing a long period of volcanic activity in early or middle Mesozoic time. Thick limestone formations of upper Eocene and Oligocene age unconformably overlie these lavas. During Miocene time these rocks were very strongly deformed, and minor intrusions of quartz diorite, which cut through the basement volcanic rocks and into the lower part of the upper Eocene limestone, probably accompanied this deformation. Doubtless some folding or warping had occurred during Oligocene or earlier periods, but the results of any earlier deformation, either in the volcanic rocks or in the limestones, could not be differentiated from those of the later periods. The folding and intrusion were accompanied by fracturing of the intrusive porphyries and of the overlying volcanic rocks, and mineral-bearing solutions found access to the fissures thus formed. Contact-metamorphic ore bodies were formed in the limestone close to the intrusive porphyries.

Normal faults, some of which are of considerable magnitude, were formed during a later period of tension. Some hot spring waters found their way toward the surface along these later fault lines.

During and after Pliocene and Quaternary time the region was elevated and eroded and some of the fissure veins were probably enriched. The erosion has continued until the present time and has cut deep, narrow valleys in the limestones that border the region. From 500 to 1,000 meters of Tertiary limestones have been eroded away from the central part of the region, thus exposing the underlying lavas and the intrusive rocks with their accompanying mineral deposits. (See geologic map, Pl. II, in pocket.)

SEDIMENTARY ROCKS.

The sedimentary rocks in the Terre-Neuve district and the surrounding regions consist of limestones of upper Eocene and middle and upper Oligocene age, which are described on pages 113, 147, 151. At some places a thick conglomerate, composed largely of cobbles of the underlying volcanic rocks, lies at the base of the upper Eocene limestone. In the central part of the district, where most of the ore deposits are found, this conglomerate is very thin; at many places it can be detected only by very careful search, and at others it appears to be absent. At most places in the central part of the district where the limestone has been preserved from erosion pure massive upper Eocene limestone generally rests directly on the old, eroded surface of the volcanic rocks. This pure limestone was easily replaced by the mineral-bearing solutions that formed the contact-metamorphic ore bodies.

IGNEOUS ROCKS.

General Features and Age.

The igneous rocks in this region comprise an older volcanic series and a younger intrusive group. The older volcanic rocks have a wider range in mineralogic and chemical composition and are much more extensive in distribution than the intrusives. The lavas range in composition from basalts to dacites, but andesites predominate. The complete order of eruption is not known, but some of the basaltic rocks are younger than the andesites and dacites. (See pp. 280-281.) The overlying upper Eocene limestone helps to obscure the structural relations of the different types of volcanic rocks, and detailed work would be necessary to establish accurately the relations of the rocks in this series. Lavas and associated rocks of this volcanic series form the basement of the Tertiary sedimentary rocks over a large part of northern Haiti. Rocks of the same mineral composition and texture as those of the Terre-Neuve region are found in the basement volcanics from Terre-Neuve northeastward to Le Borgne, on the north coast.

The younger intrusive rocks, which are of particular interest in the discussion of the ore deposits, are confined to a narrow northwestward-trending line of intrusive masses, which are barely exposed by erosion. They extend northwestward from Memé Valley for a distance of 10 or 11 kilometers, into the drainage basin of Rivière Colombier. In general the rocks range in composition from quartz diorite to basic granodiorite and in texture from granitoid rocks to dense porphyritic rocks resembling lavas. More diverse types, such as pegmatites and aplites, are found in minor quantities.

The andesitic lavas in the Terre-Neuve district and vicinity are older than the upper Eocene limestone, and lavas of similar composition and texture west of Grande-Rivière du Nord are known to be older than

Upper Cretaceous and underlie rocks of supposed Lower or Middle Cretaceous age. These andesitic lavas of the volcanic basement are probably in general of the same age throughout the northern part of the Republic, and hence the eruption of the andesites of the Terre-Neuve district is tentatively assigned to Jurassic or Lower Cretaceous time.

The younger intrusive quartz dioritic rocks cut the upper Eocene limestone and are tentatively assigned to late Miocene time because of the alinement of the intrusions with the tectonic trends produced during folding of supposed late Miocene age.

Volcanic Rocks.

Pyroxene andesites.

The pyroxene andesites constitute most of the lavas in the vicinity of Morne Macat and in the valley of Rivière Lhormand south and west of Morne Piton, and extend westward to Moulin and the base of Morne Découflay. In these regions the basal conglomerate of the upper Eocene limestone, in places several hundred meters thick, is composed very largely of cobbles of pyroxene andesite.

Andesites of this type outcrop elsewhere in the Terre-Neuve district, although not usually in such predominating proportions as in the east and northeast parts of the region shown on the map (Pl. II). Several flows of glassy, much sheeted pyroxene andesites are exposed on the east slope of Morne Dumuraille, northeast of Memé village. The sheeting and flow structure dip rather steeply to the southwest into the mountain side and under the upper Eocene limestone, which caps the crest of the mountain.

The volcanic rocks at Dolan, south of Terre-Neuve village, consist in part at least of pyroxene andesites.

The petrography of these rocks and their distribution elsewhere in the northern part of the Republic is described in Part II. (See pp. 272-277.)

Hornblende dacites and andesites.

In the Colombier Valley, in the vicinity of Terre-Neuve village, and in the region extending northward to Morne Raboteau and Rivière Bras-à-Droit, the rocks are principally reddish, much altered and weathered lavas, which were for the most part hornblende-bearing andesites and dacites. These rocks belong to the same series as the pyroxene andesites, although they differ in mineral composition. A description of the petrography of these lavas is given on pages 278-279, and altered rocks of this type are described on page 455.

Basaltic rocks.

Basalts are abundant in the pre-Tertiary volcanic complex in some parts of the Republic but are subordinate to andesitic rocks in the re-

gion around Terre-Neuve. Basaltic rocks are exposed northwest of Terre-Neuve village in the valley of Rivière Bras-à-Droit, in Section Moulin, and on the northeast slope of Morne Découflay. All are of similar petrographic character and resemble the basaltic lavas near Ennery. The age of these basalts is not known, but they are probably younger than the andesites. Some of the basaltic eruptions may be as late as early Eocene in age. (See p. 286.)

Mode of occurrence.

Most of the older Mesozoic lavas consist of relatively thick flows with a rather small amount of interbedded pyroclastic débris. No large beds of volcanic débris were found, nor were any structures resembling central vents or fissures discovered. Some of the basaltic rocks are relatively coarse-grained and probably are intrusive into the andesites, but definite structural evidence of this was not found.

Intrusive Rocks.

Quartz diorite and granodiorite.

Rock types which can be strictly termed quartz diorite or granodiorite are not abundant among the intrusives exposed in this district.

Small stocks of quartz diorite, probably not more than several hundred meters in length, are intrusive into limestone and volcanic rocks in the vicinity of habitation Hilaire, southeast of Terre-Neuve village. In Memé Valley basic granodiorite is exposed at the surface only in dikes or intrusive masses of small size. Fine-grained porphyritic modifications of the intrusive are much more abundant.

Petrographic descriptions of the quartz diorite and granodiorite and chemical analyses of the grandiorite are given on pages 301-306. The quartz dioritic facies seems to be more extensive in distribution than the granodiorite at the exposed surface of the intrusion.

Dacite porphyries.

Fine-grained porphyries, which apparently were formed by quick chilling of the first part of the intrusive magma as it came in contact with the colder overlying rocks, are the most widely distributed and characteristic form of the intrusive in the Terre-Neuve district. These porphyries constitute the bulk of the rocks shown on the geologic map under the intrusive group.

The porphyries are generally light to dark gray or greenish gray, and on weathered surfaces are stained yellowish or brownish. They may be much jointed and separate into platy fragments or into small irregular blocks, a feature characteristic of many of the larger exposures in this region. As a result of the jointing the outcrops, especially on steep hillsides, crumble away into a talus of small fragments. This jointing is no

doubt due to differential contraction that presumably took place while the rock was cooling, after the magma had consolidated.

Much of the porphyry has been considerably altered, as the joints often served as channels for solutions escaping from parts of the still molten magma below. In places this alteration is so far advanced that the porphyritic texture is nearly obliterated and the rock is so much bleached that it can hardly be recognized in the field as porphyry. These alterations are described in more detail under the discussion of contact metamorphism. (See p. 439.)

The Miocene (?) intrusive rocks appear to be a series of stocklike intrusions elongated or oriented along a line of arching. The apexes of these stocks have been barely truncated by erosion. When the magma reached the base of the upper Eocene limestone it was quickly chilled, but it seems to have spread out laterally at some places along the contact of this limestone with the underlying igneous rocks and to have formed small bodies of undetermined shape and extent.

Structure.

Folds.

The Montagnes de Terre-Neuve are described on page 120 as a broad, gentle anticlinal arch trending northwestward. The major structural features in the central part of this district have been largely formed by folding and only in a minor degree by attendant faulting. The crest of the main anticlinal arch of the mountains coincides closely with the zone of intrusion of the quartz diorite, which trends about N. 40° W.

Although the folding as a whole is rather open, along some localized zones closely compressed folds are found, and at places they pass into thrust faults. Where the folding is asymmetrical or where thrust faulting has taken place the thrust seems to have come from the southwest. The crest of the major arch of the Montagnes de Terre-Neuve is somewhat modified by a synclinal fold, the axis of which passes through the Memé and Terre-Neuve valleys. (See Figs. 27 and 28.) At Morne Miguinda this trough is asymmetrical and is broken along its western limb into faults of uncertain character, probably of minor throw, which have produced much brecciation and contortion of the beds.

Faults and fissures.

Considerable faulting and fracturing of the volcanic and intrusive rocks has occurred and it was probably in part genetically related to the folding and in part to tension after folding. The intrusive porphyries are fractured as the result of cooling after consolidation of the magma.

The relations of the many fractures to the folding are complex, and it would require considerable study to work out their details. It seems quite certain, however, that most of the fissures in which the veins were

formed are genetically related to the intrusion and folding. The larger, more open veins whose trends correspond to the axial trends of the folds may have been produced along shear zones by high-angle thrust faulting or by tension along the crests of the anticlinal folds. Relatively large open fissures with a northwest strike were seen at Ravine Jeanty. The veins here contain abundant clayey gouge and give evidence of considerable movement subsequent to the mineralization. The origin of these fissures is not readily determinable, however. More tightly closed fractures of little throw were examined at Rocher, just east of Terre-Neuve village, and may be of the conjugate type produced by compression. These latter veins in general strike northeastward and dip northwestward and southeastward. They are narrow, generally only a few centimeters in width.

Some normal faults probably are of later origin than most of the mineral deposits. Such faults were seen at Memé Valley. Farther east there is considerable normal faulting. (See pp. 470-471, and Fig. 27, *AA'*.) These large normal faults were channels that permitted the escape of hot spring waters (see pp. 470-475) but they do not exhibit mineralization of the higher temperature type, as do the veins of the Terre-Neuve Valley. The normal faulting probably was of very late Miocene or of Pliocene age. The region to the east, between the Montagnes de Terre-Neuve and the Massif du Nord, was downfaulted, bringing the Oligocene limestones down to the level of the older volcanic rocks at either side of the valley of Les Trois Rivières.

RELATIONS OF STRUCTURAL FEATURES.

There seems to be a close relation between the arching of the Montagnes de Terre-Neuve and the intrusion of the quartz diorite, as the intrusion closely coincides with the crest of the arch. At the time of the intrusion fractures were produced in the country rock that were probably genetically related either to the folding or to the forces of the intrusive magma. There is little or no evidence as to whether the later normal faulting was due to a collapse resulting from the withdrawal of the magma from beneath the region or to other causes. So far as known no extensive volcanic eruptions occurred in this region during Miocene time.

History of Mining Development.

The presence of iron and copper near Terre-Neuve was known probably as early as the seventeenth century. According to Moreau de St. Méry,[1] ruins, instruments, and uncovered iron deposits, indicating mining and metallurgic operations, possibly by Spaniards, were mentioned as early as 1728. After the beginning of the nineteenth century

[1] Op. cit., vol. 2, pp. 81-84.

little attention seems to have been paid to the exploitation of the mineral deposits here until 1898. At that time the attention of Miguel Boom, of the Department of Public Works, was drawn to the deposits by some samples of iron and copper ores that were sent to him. These samples were analyzed in New York, but the investigation came to an end owing to his death.[1]

Edmond Roumain, of Port-au-Prince, who was connected with this investigation, became personally interested in the region and collected samples. They were assayed in New York, and some showed from 20 to 40 per cent of copper.[2] He applied for a mining concession covering the district. On the strength of Roumain's examination and samples a syndicate called the "Terre-Neuve Company" was formed in New York in 1899, with an authorized capitalization of $5,000,000. The company succeeded in raising a small sum and employed engineers, who examined the properties and reported unfavorably. This company was then dissolved.

In 1900, L. Gentil Tippenhauer, formerly engineer in chief of the Department of Public Works, made a topographic and geologic map of the region by means of compass and paced traverses.[3] His map is remarkably accurate, considering the methods of surveying employed, and was used as a base for the geologic map accompanying this report.

Between 1901 and 1905 a number of attempts were made to open up and work the mineral deposits both by Edmond Roumain and by outside parties, but all attempts were unsuccessful.

In 1905 a Haitian corporation was established in Port-au-Prince called the "Compagnie Minière de Terre-Neuve," with Edmond Roumain as president. This company obtained control of the mining concession covering the entire district. Considerable prospecting was done, but after several years work was discontinued.

In 1910 a report was published in the Moniteur by F. Doret on the condition of the mines at Terre-Neuve.[4] This report to the Secretary of State for Public Works was based on an examination which Doret had been commissioned to make in 1909 as a result of misunderstandings about operations at Terre-Neuve. Exploitation had been discontinued at this time. Doret reported that the company had stopped shipping in order to improve roads, do development work, and consider plans for milling and concentrating ore on the ground.

In 1910 the "Hayti Mines Company" was incorporated in New York with an authorized capitalization of $1,000,000.[5] This company took over control of the Compagnie Minière de Terre-Neuve, which held

[1] Tippenhauer, L. G., Petermanns Mitt., Band 47, p. 121, 1901.
[2] Idem.
[3] Idem, pp. 121-127, pl. 10, 1901.
[4] Report addressed "Á M. Le Secrétaire d'État des Travaux Publics": Le Moniteur, Nos. 24 and 25, Mar. 23 and 26, pp. 153-154, Port-au-Prince, 1910.
[5] Weed, W. H., The Mines Handbook, vol. 15, p. 1990, 1922.

the concession from the Haitian government. Some work has been done on the concession since that time, principally on the contact-metamorphic deposits at Memé. Information obtained through the Department of Public Works in October, 1922, shows that 436 tons[1] of ore has been exported by the Compagnie Minière de Terre-Neuve. The work has been intermittent and was finally discontinued altogether before 1920.

Although this is not intended to be a complete outline of the rather involved history of this district, it will serve to give some idea of the interest that has been taken in it. It is roughly estimated from observations made during the present examinations that in work on both contact-metamorphic and vein deposits up to 1920, about 450 meters of tunnels had been driven and about 100 meters of short shafts had been sunk. Several open cuts, numerous strippings, small pits, and short openings also had been started. Unfortunately, much of this prospecting has been done unsystematically because of lack of proper technical advice.

General Character and Extent of Deposits.

The two principal types of mineral deposits found in the Terre-Neuve district are the contact-metamorphic deposits in limestone and the fissure veins in the volcanic and intrusive rocks. The contact-metamorphic deposits contain principally iron and copper together with small amounts of silver and gold. The fissure veins contain copper, silver, and gold, and small amounts of lead and zinc. These deposits are confined to a zone trending northwestward and bordering the intrusions of quartz diorite and dacite porphyries. This zone has a length of about 10 kilometers and a maximum width in the vicinity of Terre-Neuve village of 3 to 4 kilometers. (Pl. II, in pocket.) The close association of both the contact-metamorphic bodies and the metalliferous veins with masses of the intrusive porphyry clearly indicates that the mineralization was a consequence of the intrusion.

That a correspondence exists between the distance from the center of intrusive activity and the temperature of formation of the different types of deposits is evident. The relative temperatures at which the deposits were formed is inferred from the mineralogic associations, particularly from the presence of certain characteristic minerals. The contact-metamorphic deposits, which were doubtless formed at the highest temperature, are found at Brésillac, Hilaire, and in Memé Valley, either capping or bordering the masses of intrusive porphyry. They were presumably the first deposits formed. The oxides and silicate minerals of these deposits were formed at high temperatures during the early stages of metamorphism, whereas the metallic sulphides were formed predominantly at lower temperatures during the later stages of metamorphism. The highest-temperature vein deposits are those near Jeanty Ravine and

[1] Tons of 2,000 pounds, avoirdupois, converted from French pounds.

are found principally in the intrusive porphyries. These veins contain chalcopyrite and some specularite in a gangue of quartz and calcite. These veins were presumably formed shortly after the intrusion of the porphyries. They show no secondary enrichment. Veins at Rocher and northeast of Terre-Neuve village, a kilometer or two southwest of the main line of exposed intrusive bodies, had a somewhat lower temperature of formation than those at Jeanty. They contain sphalerite, galena, bornite, some chalcopyrite, and secondary copper sulphides and carbonates in a gangue of quartz and barite. These veins cut intrusive dikes of dacite porphyry, but their relations in time to the formation of the contact-metamorphic bodies and to the veins formed at higher temperature near Jeanty is not known.

Veins at Dolan, about 3 kilometers southwest of the main intrusive line, show that the conditions which existed there during the periods of vein enrichment were somewhat different from those which existed near Terre-Neuve village. They are characterized by native copper, cuprite, and chrysocolla. The primary character of these veins has been destroyed.

Contact-Metamorphic Deposits.

General features.

Zones of contact metamorphism have been formed at many places along the contacts of the intrusives with both the volcanic rocks and the overlying Tertiary limestones. In the volcanic rocks these zones are small or of negligible importance, but in the limestone metamorphic zones of considerable width may be present. The contact type of metalliferous deposit carrying copper and iron is found in these metamorphic zones in the limestone. These deposits were formed under relatively high temperature and pressure by hot solutions that rose from the intrusive mass below and deposited part of their mineral content under favorable conditions, such as were found in some of the bodies of limestone. Structural features, such as joint planes in the intrusive rocks, bedding planes in the limestone, contact surfaces, dikes, and fissures, may have controlled or influenced the course of the mineral-bearing solutions and may thus have been of importance in determining the zones of more intense metamorphism. That such factors have influenced the position of some of the ore bodies in the Terre-Neuve district is evident at a number of places.

A characteristic feature of the contact-metamorphic zones is the partial replacement of the limestone by silicates, metallic sulphides and oxides, and quartz. The rock of complex mineral composition thus formed by the replacement of limestone by material derived from an intrusive rock has been called tactite,[1] and in the following discussion this term will be frequently used to avoid cumbersome phrases.

[1] Hess, F. L., Tactite, the product of contact metamorphism: Am. Jour. Sci., 4th ser., vol. 48, pp. 377-378, 1919.

Except for small veinlike bodies in marble that follow the walls of porphyry dikes at Memé, all the known tactite bodies in the Terre-Neuve district lie at or very near to the contact of limestone and intrusive dacite porphyries or quartz diorite. The width of the tactite bodies in the Terre-Neuve district ranges from a fraction of a meter to 10 or 15 meters. Some of the exposures of the tactite are wider, owing to the attitude of the body, and in some places the thickness may actually exceed these figures. Some of the bodies are rudely tabular in shape but are discontinuous; many are very irregular, possibly because they follow irregular structural features in the country rock or were formed by selective replacement of certain portions of the limestone.

FEATURES OF THE METAMORPHISM.

Mineral Composition of the Tactite.

The tactite ranges from dense uniform-textured rocks to coarse irregular-textured rocks with large crystals of garnet, iron oxides, or calcite. Rocks rich in garnet are yellowish or brownish; those rich in epidote, chlorite, or nontronite are green. The rough banding in some specimens may be due to replacement along bedding planes or parallel fractures.

The most abundant silicates are garnets and epidote. The garnets are reddish to yellowish brown and in composition are possibly mixtures of the grossularite and andradite molecules. The refractive indices generally range from 1.82 to 1.84. In one specimen having notable birefringence, $\alpha=1.79$, $\gamma=1.81$. Although epidote is in general less abundant than garnet, in some of the tactite it is more abundant or present to the exclusion of garnet. Where the metamorphism has affected igneous rocks near the contact, epidote is invariably present and is deeply colored. Chlorite is common in the tactite, though usually in minor amounts. Much of it occurs in flakes which have the optical properties of penninite and are arranged in radial or spherulitic growths. In some specimens chlorite is an alteration product of epidote. Diopside was seen as small granules in only one specimen of tactite. Hornblende was found only in rocks formed by replacement or alteration of igneous rocks in the contact zone. Titanite is commonly present and forms several per cent of some rocks. A mineral that is probably nontronite is present in much of the tactite. Nontronite, a hydrated silicate of ferric iron of variable composition, is a fibrous or flaky mineral that has moderately strong birefringence (0.025 to 0.030), parallel or nearly parallel extinction, and positive elongation. It is pleochroic; X = colorless or straw-yellow; Z = olive-green or brown-green. It is optically negative, 2V small. Its indices are variable, but usually $\gamma=1.62$ to 1.66. It usually accompanies quartz or calcite and forms veinlets or flaky aggregates replacing earlier formed minerals. A small amount of orthoclase (adularia) accompanies quartz at one locality. Apatite is invariably present in small quantities and locally forms several per cent of the rock.

Quartz is almost invariably present, though in variable quantities, and in some parts of the tactite it is abundant. It is commonly accompanied by chlorite and contains inclusions of apatite and titanite. Calcite is an important constituent of the tactite and may be the predominant mineral.

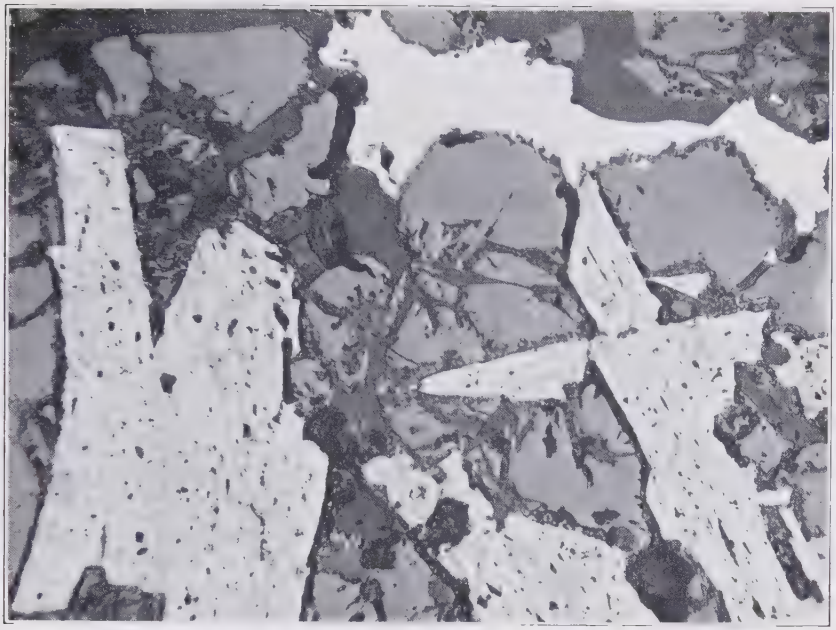
The iron oxides magnetite and hematite are the most abundant metalliferous minerals. Large bodies predominantly of magnetite and specularite are found in parts of the tactite. Chalcopyrite is the principal copper mineral. Bornite occurs in very small quantities and is secondary after chalcopyrite. Pyrite is abundant locally.

Scheelite, which is found in some contact-metamorphic deposits, is not present in the Terre-Neuve tactite. Its absence was confirmed by negative results of assays for tungsten on the ore samples which were made by Ledoux & Co., of New York. (See p. 447.) A large proportion of iron oxides in contact-metamorphic bodies apparently is generally not favorable to the presence of scheelite.[1]

The order of formation of the minerals generally is as follows: Specularite, garnet, magnetite, epidote, pyrite, quartz with chlorite, apatite, or nontronite, and finally chalcopyrite and calcite. Titanite usually appears to accompany quartz. Pyrite less commonly accompanies chalcopyrite and calcite. This general rule is not invariably followed, and in places the order may show repetition. One of the noteworthy features of the mineral paragenesis is the widespread replacement and intergrowth of the primary specularite and the later magnetite and the partial or local replacement of the magnetite in turn by later generations of hematite crystals. A very late generation of hematite in microscopic crystals probably was deposited by descending surface waters. (See Pls. XXXIII, *A* and *B*, and XXXIV, *A*.) The replacement of magnetite by later quartz, calcite, and nontronite is very marked in parts of the tactite. Calcite has in places completely replaced magnetite, either in its own crystal form or that of specularite, leaving only outlines or ghosts of the original crystal form. This deposition of calcite, which accompanied or followed the formation of chalcopyrite, was one of the important stages of the metamorphism and has resulted in some places in the nearly complete destruction of evidence of some of the earlier stages. This overlapping of the stages or zones of metamorphism is also illustrated in the metamorphism of igneous rocks near the contact, where complete replacement of early actinolitic or fibrous hornblende by later quartz and calcite has occurred. These later replacements doubtlessly occurred with falling temperature and with the accompanying or resulting changes in composition of the solutions.

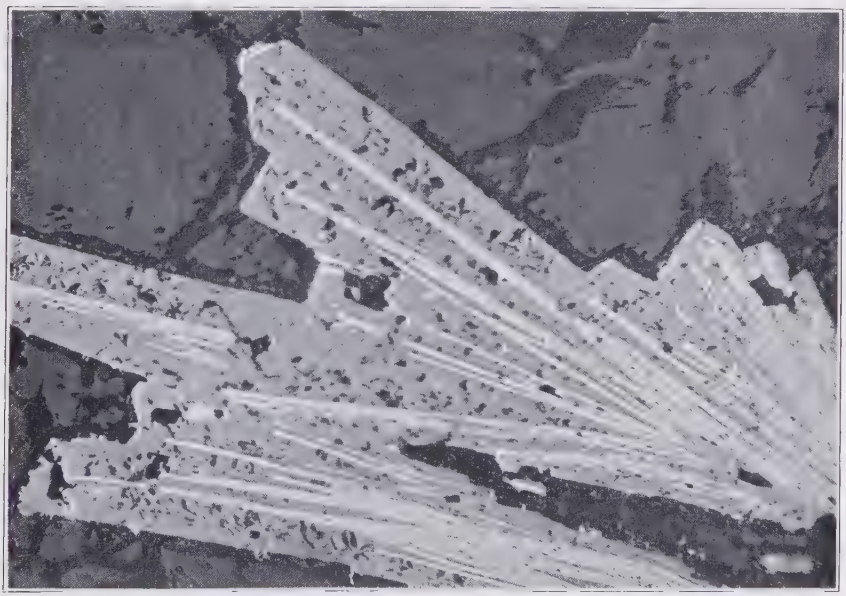
Oxidation and enrichment have played only a minor part in the formation of the contact deposits. Along fractures and at the surface oxidation

[1] Hess, F. L., and Larsen, E. S., Contact-metamorphic tungsten deposits of the United States: U. S. Geol. Survey Bull. 725, p. 249, 1922.



A. CHALCOPYRITE (WHITE), SPECULARITE PLATES (GRAYISH WHITE) IN GARNET (LIGHT GRAY), AND CALCITE (DARK GRAY).

The specularite shows incipient replacement by magnetite (gray). ×100.



B. SHEAF OF SPECULARITE BLADES LARGELY REPLACED BY MAGNETITE (GRAY).

Upper and lower left ends of blades show small amount of hematite of later generation. Gangue is garnet (gray) and calcite (dark gray). ×110.

ORE FROM CONTACT METAMORPHIC DEPOSITS, ROCHE GLISSÉ, MEMÉ VALLEY.

has resulted in partial destruction of the primary sulphides. Small amounts of bornite, chalcocite, malachite, and azurite are found at several places. Limonite and probably some of the later hematite were formed by descending surface waters.

Metamorphism of Igneous Rocks.

At habitation Hilaire, near the Casseus prospect, the quartz diorite intrudes the andesites, and contact metamorphism of both the intrusive and the country rock has occurred. A garnet-epidote rock containing large plates of specularite and some magnetite was formed. The contact zone is a few centimeters to a fraction of a meter in width. The altered rock consists largely of epidote, garnet, quartz, and calcite. Epidote was formed here earlier than the garnet. Quartz and calcite were formed during later stages and in places have a fibrous structure, inherited from replacement of uralitic or actinolitic hornblende. A little pyrite was noted but no chalcopyrite. The quartz diorite for a short distance from the contact is bleached light yellow.

Metamorphism of igneous rocks was seen at several other localities, but the changes are much the same. The zone of alteration and replacement is characteristically much narrower than in limestone. At all localities this metamorphism was found only adjacent to bodies of limestone and tactite. The metallic minerals are not developed to the extent found in tactite bodies in the limestone, probably on account of the greater resistance of the igneous rocks to solution and replacement.

Alteration of Intrusive Porphyries.

Alteration of the intrusive rocks themselves, although in places very intense, is not accompanied by an appreciable concentration of metalliferous minerals. Alteration has affected large bodies of intrusive porphyry next to the contact-metamorphic bodies.

Near Brésillac Ravine tactite bodies cap a mass of much-altered fine-grained porphyry, which is closely jointed. The solutions that caused the metamorphism of the limestone must have traversed the underlying porphyry. This is indicated both by the structural relations of the porphyry and tactite and by the intense alteration of the porphyry. In places the porphyry is bleached to a light-gray or grayish-white rock of felsitic texture in which the original porphyritic texture is almost completely obliterated. The altered rock is hard and rather dense, chips off with a nearly conchoidal fracture, and breaks into angular joint blocks. A microscopic examination of this rock shows a more or less complete albitization of the plagioclase and a destruction of the ferromagnesian minerals, whose constituents have been largely removed, with the exception of titanium, which remains behind as titanite. The rock appears to contain considerable quartz.

Altered porphyry at Memé Valley shows some mineralogic differences. The rock is medium to dark gray or greenish gray and distinctly porphyritic. Epidote and pyrite can commonly be seen with the eye in much of the more altered porphyry. Microscopic examination shows albitization of the plagioclase and development of sericite. The primary uralitic hornblende has been partly destroyed in the more altered rocks, and its destruction has been accompanied by the formation of calcite and chlorite and the separation of titanite and iron oxides. Considerable secondary orthoclase is found in some parts of the porphyry and replaces the feldspars, quartz, and groundmass, or occurs in veinlets accompanied by quartz. It is significant that although the fine-grained porphyry in Memé Valley is much altered, dikes of basic granodiorite, which intrude the porphyry and are part of the same intrusive series, are remarkably fresh.

Alteration of Limestone to Marble.

Near the igneous contacts and especially near tactite bodies the limestone is usually recrystallized to marble—that is, to a rock consisting of granular calcite. Near tactite bodies in Memé some of the marble contains small veins of quartz and nontronite. The quartz replaces calcite and is accompanied in some places by small cubes of pyrite, and some titanite and apatite. Coarsely crystalline sheeted marble was seen at the head of the valley of Rivière Bassin.

ORIGIN AND FEATURES OF THE MINERALIZING SOLUTIONS.

The mineralizing solutions were derived mainly from the quartz diorite or granodiorite intrusives. The fine-grained and porphyritic texture of the intrusive porphyry, which is in contact with the tactite bodies at a number of localities, indicates that it cooled rather quickly on reaching its present position. It seems certain that this quickly chilled rock, which constitutes the bulk of the intrusive rock exposed in the Terre-Neuve district, was not the immediate source of the mineralizing solutions, but that in all probability they came from masses of more slowly cooling magma at greater depth. Slow cooling and crystallization at greater depth permitted separation of the magmatic water and more volatile constituents, and they escaped upward, carrying with them some of the metallic content of the original magma. The upper part of the intrusive porphyry, although still very hot, was undoubtedly for the greater part solidified before the principal upward movements of the mineralizing solutions occurred. The solidified porphyry during its cooling had become considerably fractured and offered a ready channel for the solutions passing outward under pressure. The intrusive bodies at most of the localities are relatively narrow and probably formed a fracture channel within which a large bulk of the escaping solutions were confined by the more massive less-fractured walls of the older volcanic rocks. The action or

passage of the solutions was not, however, totally confined to this zone, as solutions undoubtedly permeated much of the surrounding less-fractured volcanic rock and resulted in some alteration.

The conclusion that the same solutions caused both the principal alterations of the porphyry and the metamorphism of the limestone seems unavoidable, both because of the overlying position of the altered limestone with respect to the porphyry and because the porphyry is invariably more intensely altered in the vicinity of the contact deposits.

The formation of the deposits began at relatively high temperatures, as is indicated by the presence of such minerals as garnet, epidote, magnetite, and specularite. Previous investigations seem to indicate that the temperature of formation of such deposits is from 300° to 600° C.[1] The formation of the metallic sulphides followed as the temperature of the solutions decreased.

DISTRIBUTION AND STRUCTURAL FEATURES.

Deposits of the contact-metamorphic type are known at three localities in the Terre-Neuve district: at the northwest limit of the known intrusive zone at Brésillac Ravine, near habitation Hilaire, and at the southeast in Memé Valley. Jeanty is along the line of the main intrusion, but no bodies of tactite are found either because they have been eroded away or because the conditions were not favorable for their formation. Other small deposits may exist, as many points along the intrusive zone were not explored.

The structural relations of the deposits to the upper Eocene limestone and intrusive porphyries are shown in Figures 27 and 28. A distinction is made in some sections between the dacite porphyries and the coarser-grained quartz diorite or granodiorite. In Memé Valley dikes of relatively fresh granodiorite can be seen at the surface cutting the altered contact porphyries. In general, coarser-grained, less-altered intrusives cut the fine-grained altered porphyries. Large bodies of the coarse-grained rocks must be present below the surface to provide a source both for the intrusive dikes and for the metamorphosing solutions.

At none of the localities does the porphyry appear to have been intruded much above the basal part of the limestone. The small size of the areal exposures of porphyry and their wide separation, combined with evidence showing the rapid cooling of the intruded rock, indicate that the intrusive body is barely exposed at the present stage of erosion. The porphyry magma on reaching the contact of the limestone and older lavas in some places appears to have spread out laterally to a small extent, quickly chilling, and forming bodies of undetermined shape, more probably of irregular than of laccolithic or sheet-like form.

That part of the body of intrusive porphyry that lies directly above the main conduit or channel through which the eruption took place was in

[1] Lindgren, Waldemar, Mineral deposits, 2d ed., pp. 722-723, 1919.

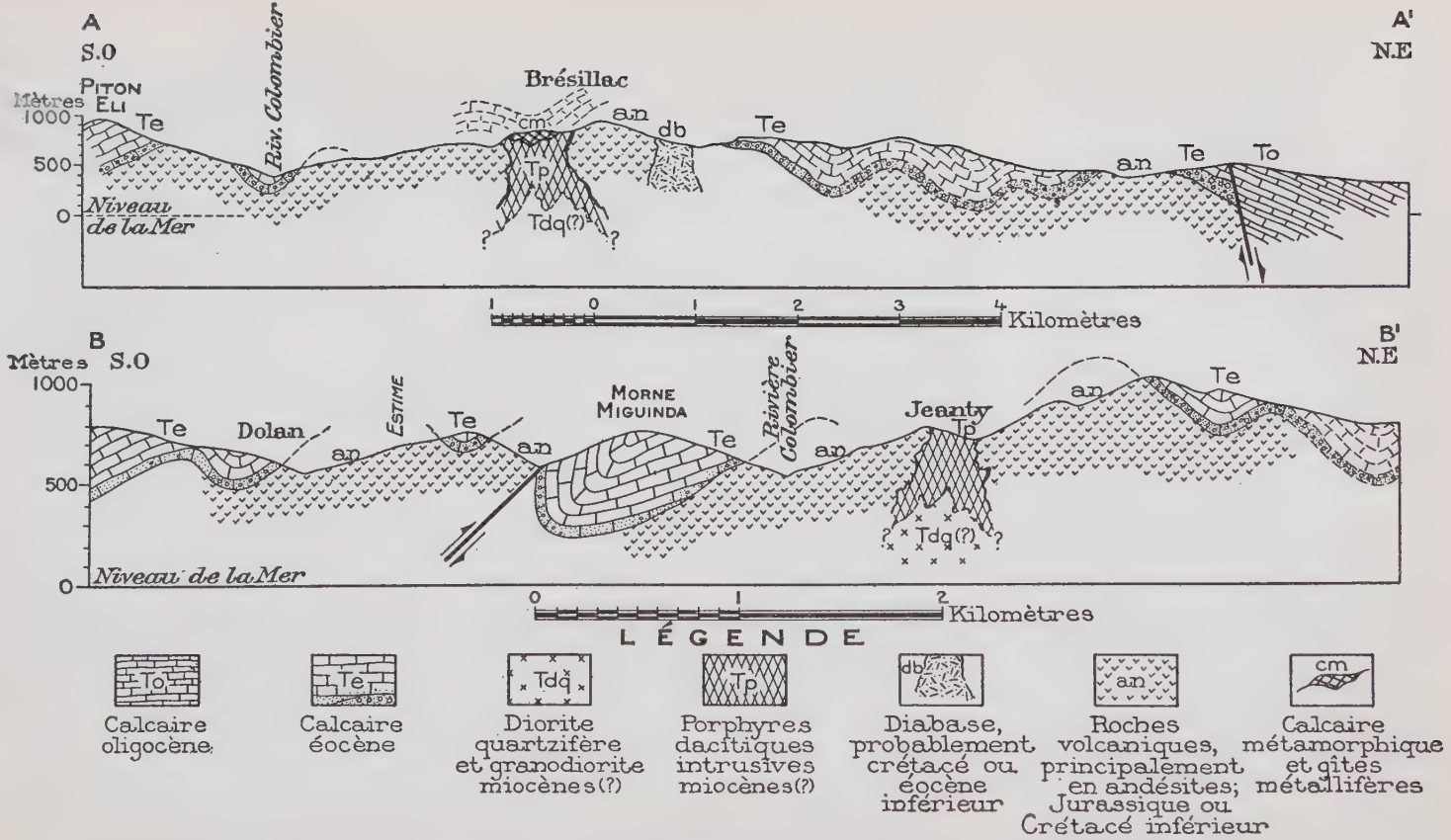


FIGURE 27.—Generalized sections showing the relations of the rocks in the Terre-Neuve district.

For lines of sections see Plate II (in pocket). The fault shown west of Morne Miguinda may be a normal fault.

a position to be intensely altered by the solutions which later rose from the molten rock below, but, on the contrary, bodies of porphyry that had moved out laterally from the center of intrusion would remain relatively unaltered. Contact metamorphism of the country rock adjacent to such unaltered bodies of porphyry is not to be expected. A significant accompaniment of all the known contact-metamorphic bodies is the intense alteration of the intrusive porphyry adjacent to them. The body of porphyry extending southeastward along the Rivière Bassin below Memé may be a body which has moved laterally from the center of intrusion near the head of Memé Valley. This relation is merely suggested, however, and has not been demonstrated by thorough field observations.

The upper Eocene limestone caps the andesitic lavas and is not engulfed in them, as postulated in some earlier reports. Hence limestone containing ore bodies will not be found below the horizon of the underlying volcanic rocks, except in downfaulted blocks of limestone or in detached blocks engulfed in the intrusive magma. This fact is noteworthy and indicates that few of the known tactite bodies in the Terre-Neuve district extend to very great depths. The tactite bodies in Memé Valley doubtless are in small blocks of limestone that were sharply infolded or downfaulted. (See Fig. 28.)

The outcrops of the tactite bodies in this region are generally conspicuous though minor features of the topography, as many of these bodies are very hard and form well-defined ridges and flat cappings on the less resistant porphyries. Bodies that contain magnetite and hematite and that are stained with limonite and copper carbonates may form part of the outcrop.

Detailed topographic and geologic mapping and a study of the geologic structure are very important steps in the exploration and development of mineral deposits of this type.

PRINCIPAL PROSPECTS.

The prospects at the head of Memé Valley known as the Roche Glissé mine (No. 1 on map forming Pl. II) and the Des Hommes prospects (No. 2 on map) are the largest workings in contact-metamorphic deposits. The Roche Glissé mine includes the Germain tunnel, a little over 20 meters in length; the Roche Glissé tunnel, which has several branching galleries having a total length of 50 to 60 meters; an open cut; and a small shaft about 10 or 15 meters in depth. The tunnels penetrate the hillside in a northwesterly direction for about 20 meters and are in marbleized limestone and tactite throughout their length. The open cut, which is on the hillside above the tunnels, shows considerable magnetite and specularite, and some pyrite and chalcopyrite. The tactite appears to be roughly banded and to dip gently into the hillside, possibly parallel to the original bedding of the limestone. Marbleized limestone continues above on the hillside for some distance.

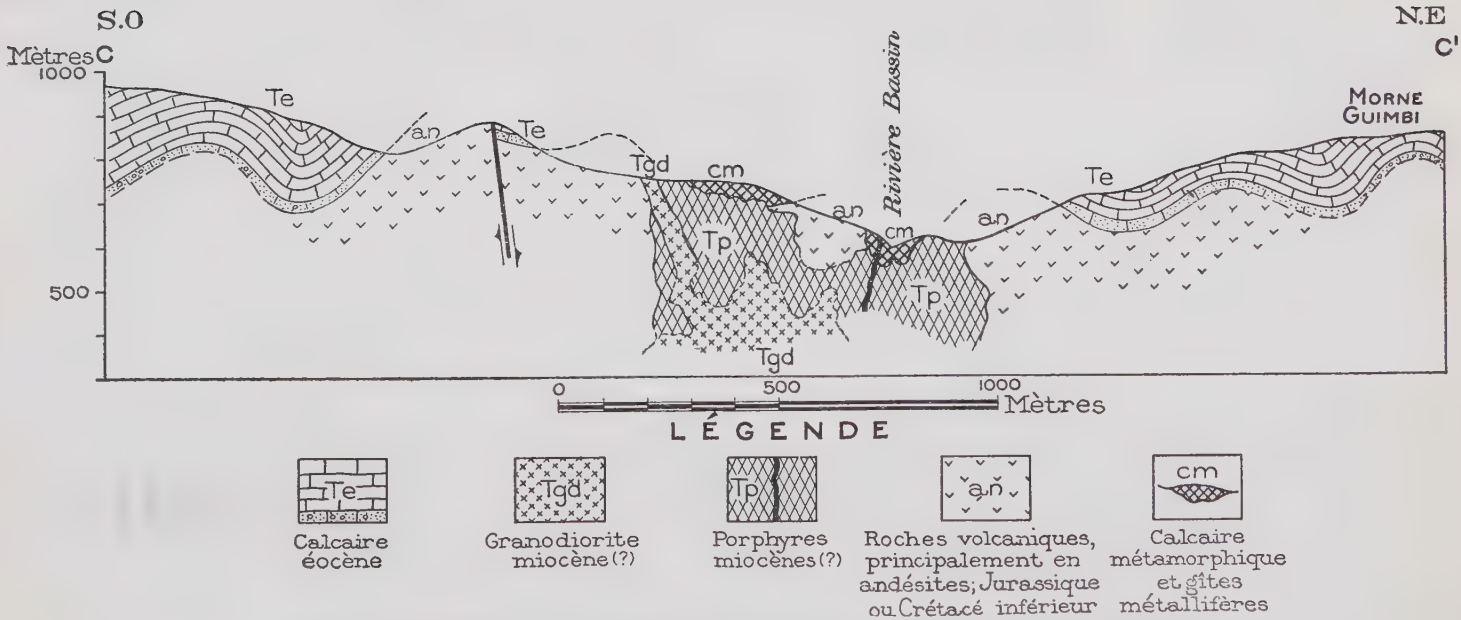


FIGURE 28.—Section across Memé Valley showing the contact-metamorphic deposits.

For line of section see Plate II (in pocket).

The Des Hommes workings consist of four principal tunnels, from 5 to 30 meters in length, a few shorter openings, and some surface strippings. Several of these tunnels are in the same limestone body as the Roche Glissé. Below, on the west side of the ravine (No. 2 on map), there are a number of short tunnels which cut across the contact of the marbleized limestone and andesitic rocks. Small, thin bodies of tactite are found along the contact of the marble with the older andesite and along both contacts of an intrusive porphyry dike that cuts the marble here. No intrusive rock is exposed west of the ravine except the dike. This dike is clearly not the agent of the metamorphism, but its contacts offered convenient vertical channels along which the mineral-bearing solutions rose. East of the ravine the altered intrusive porphyry is exposed and is capped at some places with bodies of magnetite and hematite that show a few stains of copper.

Still farther down the ravine, at La Cascade, there is a body of tactite containing a considerable proportion of pyrite and iron oxides, over which the stream cascades for 8 or 9 meters (No. 3 on map).

The workings at habitation Hilaire consist of three principal prospects, Casseus (No. 5 on map), Bosse or Damaconoute (No. 6), and Germinie (No. 7). The Casseus prospect consists of two short tunnels, the longest about 14 meters in length. The shorter tunnel exposes a contact between quartz diorite and a dark-colored andesitic volcanic rock. There is only slight mineralization at the contact. The larger tunnel was driven into a contact zone containing garnet, specularite, calcite, and some pyrite and chalcopyrite and penetrates the older volcanic rocks. The ground to the east is covered with float of the limestone that appears to be relatively unaltered, though none of this limestone was found in place. The tunnel penetrates part of the older volcanic rocks. The tactite zone here is close to the erosional contact between the limestone and the underlying andesite.

The small tunnel called Damaconoute was driven only about 10 meters into slightly metamorphosed quartz diorite. No ore body is exposed at this prospect.

At Germinie a thin body of tactite overlies the quartz diorite. The body is resistant and forms a semicircular capping to a small ridge. A short tunnel in the tactite, several meters in length, shows only a very little copper.

At Brésillac (No. 11 on map) the tactite body is a cap nearly 10 meters thick, which dips gently northward over the intrusive porphyry. There is a branching tunnel about 14 meters in length and a short opening driven into the tactite along the northeast side of Ravine Lamour. A small shaft 5 or 10 meters deep was started above on the hillside, but it seems to have encountered no particularly rich ore. Short tunnels near the bottom of the ravine were driven into the barren intrusive porphyry.

At Jean Auguste (No. 12 on map) the relations are much the same as at Brésillac: the tactite bodies are near the crest of a spur ridge above the much altered porphyry that forms the main body of the ridge. The largest ore body was worked by an open cut and appears to have been exhausted. A shallow bench was cut into the hill along a front of 25 meters or more and from 6 to 10 meters in width. Most of the ore seems to have been taken from the east end of the bench, where an irregular excavation, ranging in depth from 3 to 8 meters, was made over an area of about 60 to 80 square meters. There is a small shaft, about 4 or 5 meters in depth, at the base of the excavation, evidently sunk for prospecting after the ore body had been exhausted. According to local reports more ore was shipped from this working than from any other in Terre-Neuve Valley. Some of the longer tunnels, which were started below on the hillside, were driven into the barren porphyry for 20 or 30 meters without encountering other ore bodies.

POSSIBILITIES OF FINDING NEW DEPOSITS.

As the limestone caps the andesitic volcanic rocks tactite will probably not be found below the basal beds of the limestone. At practically all localities where intrusive rocks are exposed erosion has already cut to this level or slightly below it, and therefore tactite will probably not be found at much greater depths. Blocks of limestone may have been engulfed in the magma, but such engulfing of limestone is probably uncommon because the first intrusive porphyry was quickly chilled and because the intrusive bodies are small. Downfaulted blocks of limestone or sharply infolded synclines would be the only other structural features that might carry limestone to any great depth below the erosion surface at any of the localities where the intrusives have been found. None of the bodies of limestone or tactite examined showed much promise of extending beyond moderate depths. The limestone body in contact with the volcanic rocks and intrusive at the head of Rivière Bassin above Memé appears to be an infolded syncline or downfaulted block and may possibly extend at the upper end of the valley to a maximum depth of 30 to 40 meters. (See Fig. 28, p. 444.)

Prospectors should keep in mind the fact that the intrusive contacts between the quartz diorite or other related intrusive rocks and the limestones are the most favorable places for contact metamorphic ore bodies. At some places small bodies of intrusive rock of Miocene (?) age other than those shown on the maps may be exposed, but the intrusive zone probably does not extend along its prolongation to great distances in either direction.

TENOR OF ORES.

Only a rough approximation of the value of the ores is possible in this report because of the variations in tenor characteristic of contact deposits and the lack of a sufficient number of analyses of ore from this district.

The few samples collected during the reconnaissance (see samples 1-3 in table below) show somewhat lower tenor than samples whose assays have been previously published.

Assays of ores from Terre-Neuve district.

[Samples 1-3 (collected during this reconnaissance) assayed by Ledoux & Co., New York; samples 4-9 assayed by C. L. Constant, New York.][1]

Sample No.	Character and source of sample.	Copper.	Silver.	Gold.	Tungsten.
		Per cent.	*Oz. per ton.*	*Oz. per ton.*	
1	Chip sample for length of 14 meters, Roche Glissé, Memé.....	.98	.30	.07	None.
2	Chip sample for length of 7 meters, Brésillac tunnel	.98	.30	.03	None.
3	Chip sample from face in Roche Glissé tunnel, Memé.....	2.72	.30	.04	None.
4	General sample, Casseus prospect..	3.95	....	....	....
5	General sample, Germinie prospect.	14.85	1.14	1.8	....
6	General sample, Bosse prospect....	3.22	None.	None.	....
7	General sample, Damaconoute prospect	4.13	.03	Trace.	....
8	General sample, Pierre Louis prospect	2.69	Trace.	None.	....
9	General sample, Jean Auguste prospect	5.59	....	....	....

Samples 1 and 2 were taken in the tactite zone at two separate localities and give a rough idea of the average tenor of much of the tactite, although some scattered bodies are richer. Sample 3 was taken from a face picked to represent some of the richer bodies, but the assay is lower than most of those published by Ferguson[2] (samples 4-9 in the table). The zone of tactite doubtless contains bodies of ore that will assay 5 to 10 per cent of copper, but most of the richer bodies will probably not average higher than 3 to 5 per cent. Ferguson states that one shipment of ore from the Roche Glissé mine ran 14.8 per cent of copper and contained 3.34 ounces of silver and 0.18 ounces of gold per ton, but this ore must have been exceptional and carefully sorted. Hand sorting of the better-grade ore, running from 3 to 5 per cent, probably would not give ore for shipment averaging higher than 6 to 8 per cent except under the most favorable circumstances. In order to reach the sporadic bodies of richer ore much ore would have to be mined that would probably average not more than 1 per cent.

Magnetite and specular hematite are found in considerable amounts in the tactite zone and at many of the prospects they greatly predominate

[1] Assays of samples 4 to 9 published in Ferguson, E. G. W., The mineral resources of Haiti, West Indies: The Mining World, Vol. XXXI, p. 135, July 10, 1909.

[2] Op. cit.

over the sulphides. The bodies, however, are not large enough nor pure enough to be worked independently for iron ore. Apatite is found in the contact zone at some places where it forms a large percentage of the rock, indicating that the ore is probably rather high in phosphorus. The iron has considerable value as a flux in the copper ore and thus assists in obtaining favorable smelter rates.

In a report on the conditions of the mines at Terre-Neuve in 1909, Doret[1] states that previous to his investigation about a thousand tons of ore averaging 6 per cent of copper had been shipped from the mines near Terre-Neuve. Most of this ore was probably mined from the contact deposits and hand sorted on the ground.

COST OF LABOR AND TRANSPORTATION.

As none of the mines or prospects were being worked in 1920 and 1921, when they were visited, the cost and the efficiency of the labor available could not be determined at first hand. Local informants reported that from 1 to 2 gourdes[2] a day was the normal wage paid native laborers, and that foremen probably received from 12 to 15 gourdes per week.

The cost of transportation of ore on burros or mules from Memé to Gonaïves by way of Bassin was about 20 gourdes per ton in 1912-13, according to Lutgens.[3] He bases his estimate on a load of 200 pounds for each animal, which is somewhat excessive for continued practice. Two gourdes per trip was the price charged for each animal. A certain port charge must be paid, besides the lighterage and freight charge to New York. Exclusive of mining and treatment, the cost per ton of the ore at New York would probably be $10 to $12 (U. S. currency) with the present available means of transportation. In 1909 Doret[4] stated that ore averaging 6 per cent of copper could not be profitably shipped to the United States at the current freight rates.

The improvement of the transportation conditions between Memé and Gonaïves should be an important part of any scheme for the development of the properties.

CONCLUSIONS.

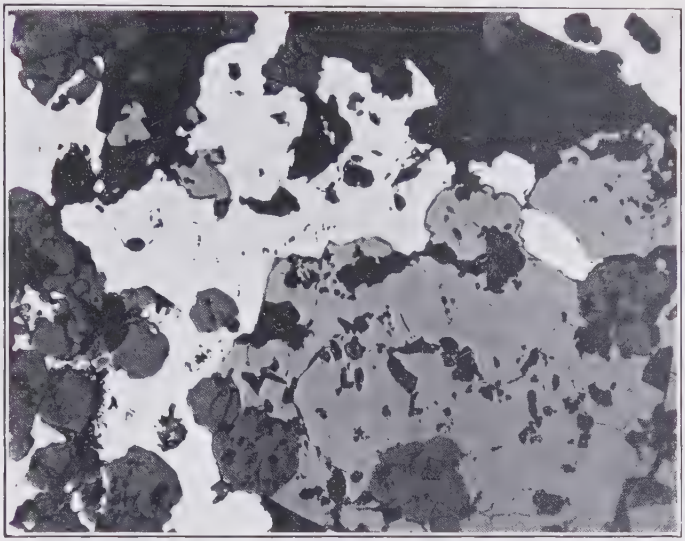
The apparent inability of the several promoters of the properties to operate them successfully, although not encouraging in itself, does not conclusively indicate that better results are not possible. Much of the prospecting and development work has been wasteful. The tactite bodies, with the exception of a few that lie along steep contacts of igneous rock and

[1] Doret, F., Report addressed "À M. Le Secrétaire d'État des Travaux Publics": Le Moniteur, Nos. 24 and 25, Mar. 23 and 26, pp. 153-154, Port-au-Prince, 1910.

[2] A gourde at rate of exchange in 1921 was equivalent to 20 cents in United States currency.

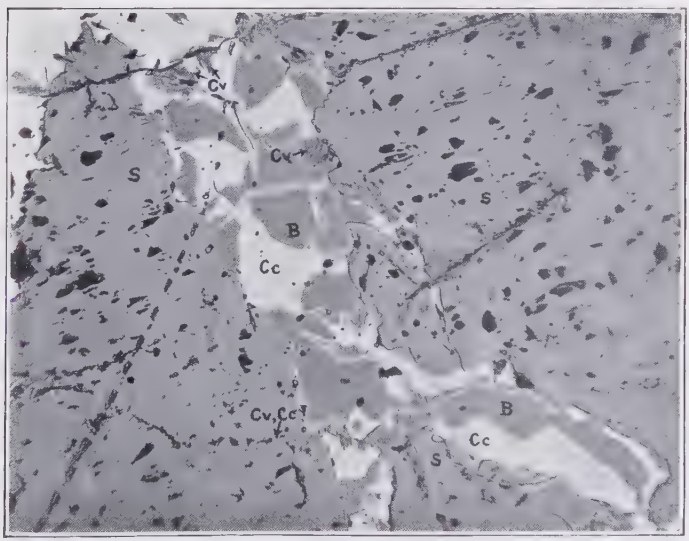
[3] Lutgens, R., Geographische und geologische Beobachtungen in Nordwest-Haïti: Geographischen Gesellschaft in Hamburg Mitt., Band 23, p. 56, 1919.

[4] Doret, F., op. cit.



A. ORE FROM CONTACT METAMORPHIC DEPOSITS, ROCHE GLISSÉ, MEMÉ VALLEY.

Magnetite (gray) and chalcopyrite (white) inclosing crystals of garnet (dark gray). The dark gangue accompanying chalcopyrite and filling cracks in garnet and magnetite is calcite. ×90.



B. SECONDARY COPPER ORE FROM ENRICHED VEIN AT ROCHER.

Brecciated sphalerite (S) partly replaced by bornite (B) and chalcocite (Cc). Also some later covellite (Cv) and chalcocite along small cracks. ×90.

limestone, are relatively flat lying and could have been efficiently worked by open-cut methods of mining. This method was employed at a few places and probably could have been more generally applied. A number of unnecessary tunnels were driven into the hillsides, some for long distances through barren intrusive porphyry.

The contact deposits in Memé Valley are the most encouraging and most favorably situated for development. None of the tactite bodies examined northwest of Morne Dumuraille in the Terre-Neuve Valley seem to offer much encouragement for further development. The few bodies that have not been extensively prospected are small and flat lying and are probably thin cappings. Moreover, the transportation in this part of the Terre-Neuve district is difficult. However, if at any time the deposits at Memé could be profitably mined, probably some ore could be taken from the deposits in Terre-Neuve Valley.

The probable low tenor of most of the tactite bodies and the uncertainty as to their size or continuity except to relatively shallow depths are factors which must be given considerable weight in judging any of the deposits. Probably most of the tactite will run between 1 and 3 per cent in copper, possibly with small scattered bodies of richer ore. Much barren rock would doubtless have to be removed during mining operations. The developing and operating of such deposits is clearly not to be attempted on a small scale. Because of the heavy gangue minerals, such as garnet and the iron oxides, the ore as mined could not be efficiently concentrated by water, and the transportation costs on the ore would be high. Possibly some methods of flotation could be successfully applied for the concentration of this ore. However, it is questionable whether the size of the ore bodies or the tenor of the ore exposed at the present stages of prospecting would warrant the considerable initial outlay necessary to large-scale operations. Although there has not been sufficient development to warrant an accurate estimate of the tonnage, the surface exposures and prospect tunnels in Memé Valley at present expose probably not more than 50,000 to 100,000 tons of ore, running from 1 to 3 per cent copper. Possible ore in addition to this will doubtless be found only within the area of limestone west of the Rivière Bassin above Memé and in the small bodies of altered limestone near the bed of the ravine. (See Pl. II and Fig. 28, p. 444.) The depth to which these partly altered limestone bodies extend is unknown. Under favorable conditions, assuming an average thickness of 10 meters for the tactite bodies, it is possible that a total of several hundred thousand tons of tactite might be present in the southeastern part of the area on the hillside above Memé and in the small bodies of limestone in the ravine of the Rivière Bassin. It is very probable, however, that the tactite bodies, if present, would be discontinuous. Thorough prospecting to determine the depth to which the limestone and tactite bodies extend and if possible their attitudes, should be undertaken before any scheme for exploitation is seriously considered.

Vein Deposits.

GENERAL FEATURES AND DISTRIBUTION.

Quartz veins carrying sulphides are found both in the intrusive porphyries and in the surrounding volcanic rocks. These veins carry copper and silver and some gold, but their richness depends largely on the amount of secondary enrichment. Nearly all the veins are rather small, some of them only a few centimeters wide, although in some places they are as much as 20 to 40 centimeters wide.

The primary veins appear to be of two types, those carrying pyrite, chalcopyrite, and specularite in a gangue of quartz and calcite, and those carrying chalcopyrite, pyrite, sphalerite, and galena in a gangue of quartz and some barite. Oxidation and leaching have largely destroyed the primary sulphide constituents of the veins of the second class to a depth of at least several meters below the surface. Both types of veins carry some silver and gold. The enriched veins carrying galena and sphalerite are the richest in silver.

The veins carrying chalcopyrite and specularite appear to have been formed at relatively high temperatures and are known in only one locality, at and near Ravine Jeanty. Here the veins are in altered porphyries and aplitic rocks. These veins show little or no evidence of chalcocitization, though there is some secondary limonite and copper carbonates.

Veins of the second type are found principally at Rocher, a short distance southeast of Terre-Neuve village. The country rock is altered andesite and a large dike of dacite porphyry.

East of Terre-Neuve there are quartz veins similar to those at Rocher, carrying bornite, chalcocite, and copper carbonates.

At Dolan, south of Terre-Neuve village, there are veins containing native copper, cuprite, chrysocolla, malachite, and azurite. The primary mineralization here is not known.

At other places small quartz stringers show stains of malachite.

VEINS NEAR ROCHER.

Character and distribution.—The veins near Rocher are confined to a small zone that extends southeastward from Terre-Neuve village toward the base of Morne Miguinda. Most of the larger veins are near habitation Rocher, although some minor copper-stained fractures are found farther east and southeast.

Most of the veins were formed by the filling of open spaces caused by fractures, though some were formed by the replacement of wall rock close to the fractures. The veins could not be traced far, and their small size indicates that they may not be very persistent either in length or depth. Only a small amount of clayey gouge is found in them, and in general there is little brecciation of the wall rock except at the intersections of

fractures. The strike of the veins is generally northeastward, ranging from N. 35° E. to N. 70°–80° E., and the dip is rather steep both to the northwest and southeast. However, some dips of only 30° to 45° were noted. The width of the individual veins probably does not average more than 2 to 4 centimeters, although some veins widen to 8 or 10 centimeters for short distances, and some impregnated breccia zones may be even wider. The country rocks are altered andesites and dacite porphyry.

Prospects.—A considerable number of small shafts, pits, and other openings have been started on these veins. The deepest shafts, however, extended to a depth of only 12 or 15 meters, and the veins are still in the zone of secondary sulphides.

The Darius No. 1 and No. 2 prospects (No. 13 on map, Pl. II) consist of two shafts about 10 and 4 meters deep, respectively, sunk on veins that strike about N. 60° E. and dip from 60° to 70° E. Near the surface at shaft No. 1 the wall rock is impregnated with copper carbonates for a width of a meter or two. The sulphide ore occurs in small quartz stringers. Shaft No. 2 exposes a brecciated zone, evidently at the junction of two fractures. The mineralization along either fracture is slight but it is somewhat more pronounced in the breccia zone. Between these two prospects a shallow pit has been dug, exposing the vein, but here it is pinched out and shows only a very slight mineralization. Just west of these fractures another vein strikes N. 70° to 80° E. and dips 30° N. This fracture had considerable red clayey gouge, but the mineralization consists of only a slight malachite stain in the wall rock. About 15 to 20 meters west of shaft No. 1 a vein that trends N. 45° E. is exposed in a small prospect pit, a meter or two deep. The vein dips 45° southeast and contains 2 to 3 centimeters of nearly solid chalcocite filling.

Farther up the ravine, about half a kilometer east of these prospects, there are several other prospect pits and one shaft about 12 meters deep (No. 14 on map, Darius No. 4 and Raphaël prospects). The veins here are small quartz stringers, generally 2 to 3 centimeters wide but at places widening to 10 centimeters or more. The quartz contains some sulphide ore and the soft altered wall rock is impregnated with sulphide and malachite. The country rock is dacite porphyry, which intrudes the older andesites. The veins strike about N. 80° W., and dip 45° N.

The Ophat prospect (No. 15), which is near the crest of a small knoll northeast of Rocher consists of a tunnel about 15 meters in length driven into the hillside at the contact of the intrusive porphyry and altered andesite. A small shaft was sunk to intersect the face of the tunnel, which was caved near the face when examined. The fault zone in some places is slightly mineralized for a width of 25 to 30 centimeters with oxidized copper minerals and some sulphides in a quartz and barite gangue. Near this prospect there was a small ore pile that contained specimens showing remnants of primary sulphide ore.

Tenor.—During this investigation a few samples of sulphide ore and of impregnated wall rock were taken. These samples were assayed with the following results:

Results of assays of samples of ore from prospects near Rocher.

[Assays made by Ledoux & Co., of New York.]

Sample No.	Character and source of sample	Copper.	Silver.	Gold.
		Per cent.	*Oz. per ton.*	*Oz. per ton.*
1	Picked sample of partly oxidized vein. Ophat prospect, Rocher	38.46	88.00	0.63
2	Picked sample of sulphide vein. Darius No. 4 prospect, Rocher	34.26	55.80	0.09
3	Groove sample of brecciated wall rock partly impregnated with sulphides. Width 1.5 meters. Darius No. 2 prospect, Rocher	0.99	0.10	0.005
4	Groove sample of wall rock, impregnated with malachite and sulphides. Width 0.34 meter. Darius No. 4 prospect, Rocher	1.73	[a]	[a]

[a] Undetermined.

Samples 1 and 2 were taken from veins that were about 4 centimeters wide and that consisted of approximately half sulphide and half gangue. These samples were selected from the more promising-looking veins, for many of the veins were either so slightly mineralized or so much oxidized as to be hardly worth sampling. Sample 1, which is the highest in silver and gold, contained remnants of primary chalcopyrite, galena, and pyrite. It consisted largely, however, of chalcocite and covellite, partly altered to malachite, in a gangue of barite and quartz. (See Pl. XXXV, *B.*) Sample No. 2 contained considerable sphalerite and some pyrite, both of which were largely replaced by bornite, chalcocite, and covellite. From these assays it appears that the sulphide ore is fairly high in silver but low in gold.

The walls are at some places near the veins impregnated with malachite, and at others with some secondary sulphides. Samples 3 and 4 were taken from impregnated wall rock at favorable appearing places. Sample 3 was collected from a breccia zone and contained some sulphide in addition to malachite.

If these veins could be mined by stopes having an average width of one meter (and the stopes could be no narrower because of the dip) it is estimated that the copper would run from 2 to 3 per cent, silver from 3 to 5 ounces, and gold about 0.005 to 0.04 ounces per ton of rock mined if we may assume that the average tenor of veins is the same as that of the samples assayed, but this assumption is not warranted by the study of conditions in the field. In fact, most of the veins merely show a few stringers of quartz containing traces of sulphides and some malachite.

The content of malachite and chalcocite in the wall rocks indicated in assays 3 and 4 would probably diminish rapidly with increase of depth.

Mineralogy.—The recognized primary sulphide minerals in these veins are chalcopyrite, pyrite, sphalerite, and galena. The gangue is generally quartz, although at the Ophat prospect earlier barite accompanies the quartz in a pyrite and galena-bearing vein. Primary chalcopyrite was found in only one specimen, which contained it in very small amount. If the other specimens collected originally contained chalcopyrite it seems to have been completely destroyed by secondary processes. Traces of a mineral that in microchemical tests[1] resembles famatinite were seen in polished sections of a specimen containing sphalerite and pyrite, taken from a vein on the Darius No. 4 prospect. These traces are so small that conclusive chemical tests of them were not possible. The mineral appears white by reflected light in the polished sections and is in a late stage of replacement by chalcocite. If the primary minerals were in part sulpharsenates or sulphantimonates, such as enargite and famatinite, most of the arsenic and antimony has been removed from the upper few meters of the veins. The conditions at the prospects favored the destruction of the primary minerals, and samples were not readily obtainable from depths of more than 5 or 6 meters or from sulphide veins more than 2 or 3 centimeters in width. The pyrite, galena, and chalcopyrite remaining in the enriched portions of the veins are much decomposed. (See Pl. XXXV, *A*.)

In the upper parts of the veins, to the depth exposed by the present prospect workings, bornite, chalcocite, and covellite are the principal sulphides. Bornite is rather abundant in the less chalcocitized sulphide ore, and, like the later chalcocite, it replaces sphalerite and pyrite. Both bornite and chalcocite at many places form veinlets cutting the sphalerite and pyrite. (See Pl. XXXIV, *B*.) The structural relations seen in polished sections suggest that the bornite was formed under the same conditions as the chalcocite and hence may have been deposited by descending meteoric waters during the period of sulphide enrichment. If so bornite was the first secondary copper sulphide to form and was followed by chalcocite and covellite. Some of the chalcocite in polished sections is a deeper blue than normal, its color being due in part to a fine intergrowth and in part, probably, to solid solution of covellite. Later generations of covellite and chalcocite, which are associated with copper carbonates, show varying interrelations. Near the surface both sulphides are extensively replaced by malachite and to a minor extent by azurite. (See Pl. XXXV, *B*.) A few microscopic veinlets of secondary chalcopyrite were seen in the bornite.

The form in which the silver occurs in the ore is not definitely known, but some of the chalcocite appears to be highly argentiferous. In polished

[1] Davy, W. M., and Farnham, C. M., Microscopic examination of the ore minerals, p. 83, 1920; Murdoch, J., Microscopical determinations of the opaque minerals, p. 99, 1916.

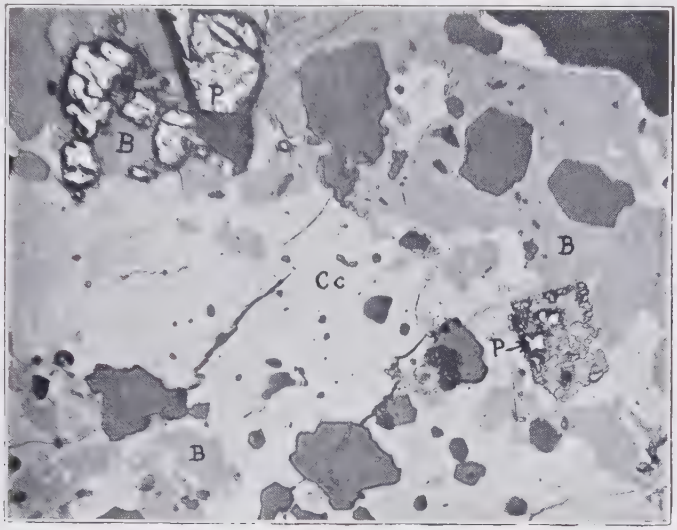
sections of sulphide ore seen under the microscope small blebs and veinlets of a creamy-white mineral, possibly native silver, cut secondary veinlets of chalcocite and bornite. In a thin section of partly oxidized ore containing considerable malachite a soft white mineral that had partly replaced covellite and chalcocite could not be definitely identified by microchemical reactions. The polished surface of the mineral was tarnished with a brownish iridescence by mercuric chloride, but owing to the presence of considerable malachite and to the fineness of the texture microchemical tests were not decisive. The mineral may be argentite ($Ag_2 S$) or dycrasite ($Ag_6 Sb$).[1] As this ore assayed 88 ounces of silver to the ton (sample 1, p. 452) the mineral is probably a secondary silver mineral deposited by descending surface waters in the upper part of the chalcocite zone. Possibly much of the silver in these rich secondary ores occurs in some unrecognized form in the chalcocite.

Enrichment.—The exact physiographic conditions under which the primary veins at Rocher were enriched can not be certainly inferred. The erosion of the overlying igneous rocks and limestones was probably well under way in late Pliocene and early Quaternary time. During this time the enrichment of the primary veins that reached the surface probably began, and this enrichment has in general probably kept pace with the lowering of the surface and of the ground-water level. It is generally held that the secondary sulphide zone is formed below the zone of oxidation and begins essentially at the ground-water level.[2] The level of the present water table at Rocher is probably close to the level of the bottoms of the adjacent ravines, although it possibly fluctuates considerably as a result of the marked differences in rainfall during the wet and dry seasons. The highest ground at Rocher stands 490 to 500 meters above sea level, and the adjacent bed of the Rivière Colombier is about 450 meters above sea level. Many of the prospects are not more than 10 or 15 meters above the bottom of the ravine. At present the chalcocite zone at Rocher extends practically to the surface, although there is slight oxidation at least to the depth of the present prospecting—10 to 15 meters. Thus it appears that erosion and consequent downward migration of the water level have gone along faster than the downward migration of the sulphide zone. This difference is due probably to less leaching and downward enrichment during a diminishing circulation of ground water, which is possibly a consequence of less relief in recent times. There is no reason to believe that the chalcocitization is going on or has taken place near the surface, as the sulphides are clearly subject to oxidation at their present position.

There is little means of judging how far the chalcocite zone extends below the present ground-water level. Because of the very small size of the

[1] See Davy, W. M., and Farnham, C. M., Microscopic examination of the ore minerals, p. 67, 1910.

[2] Emmons, W. H., The enrichment of ore deposits: U. S. Geol. Survey Bull. 625, p. 63, 1917.



A. SECONDARY COPPER ORE FROM ENRICHED VEIN AT ROCHER.

Pyrite (P), bornite (B), and chalcocite (Cc). Pyrite partly replaced by both bornite and chalcocite. Dark gray areas are quartz. ×10.

B. SECONDARY COPPER ORE FROM PARTLY OXIDIZED VEIN AT ROCHER.

Chalcocite (grayish white) and covellite (light gray) partly replaced by malachite (dark gray). At right small remnant of pyrite (white). ×120.

veins and the probable lack of vigorous meteoric circulation in recent times, the chalcocite zone doubtless does not extend to very great depths. Even if the zone extended 30 to 50 meters or more below the surface the silver enrichment is probably rather superficial and will no doubt decrease rapidly with increase of depth. In general secondary silver and gold are precipitated nearer the surface than the secondary copper minerals, in some places in the upper part of the chalcocite zone. Below the chalcocite zone secondary silver minerals will probably not be found, as chalcocite or chalcocite-depositing solutions are precipitants of both silver and gold.[1]

Alteration of wall rocks.—The wall rock near the veins has generally been somewhat bleached and altered and is impregnated with secondary sulphides and malachite.

In the dacite porphyry the formation of chlorite and to a minor extent sericite have been the principal changes which probably occurred during the formation of the primary veins. Some potash has been introduced, and some carbon dioxide to form calcite. In the more altered rock the phenocrysts of feldspar have been largely destroyed and replaced by calcite and some kaolinite. The hornblende is altered to chlorite, calcite, magnetite, and titanite or rutile. The kaolinite may be the result of weathering, as the specimens were necessarily taken within a few meters of the surface, and moreover they were liable to localized alteration by meteoric waters that descended along the vein.

In the more basic and more permeable hornblende andesites and basaltic rocks the weathering is more pronounced and more widespread. These rocks are greatly decomposed and softened to a considerable depth. The more altered rocks consist largely of calcite, ferric oxide, quartz, and a mineral that resembles gibbsite. Andesitic rock taken from places near the porphyry dike contact at Rocher shows considerable albitization of plagioclase and the introduction of quartz and some calcite. Iron occurs largely as hematite and limontite.

The kaolinite in the porphyry and the limonite and gibbsite (?) in the andesitic and basaltic rocks were probably formed by weathering, which is more pronounced along the fissures through which the meteoric waters descended.

VEINS NEAR RAVINE JEANTY.

Character and distribution.—The veins at Ravine Jeanty are quite different from those near Rocher. They are in rather wide fissures or shear zones containing a thick clayey gouge produced by considerable movement along them. Much of the vein filling is separated from the wall rock because of movements later than the mineralization, and in some veins the filling is much brecciated. The veins differ much in width at

[1] Emmons, W. H., op. cit., pp. 157, 257, 269.

different places; at some places they pinch out altogether; at others they widen to half a meter or more.

The veins are in an intrusive complex of quartz diorite porphyries and related aplitic rocks, which is intruded into the older volcanic rocks and forms a narrow zone, about a kilometer in length, trending northwestward.

Prospects.—There are reported to be 15 or 20 prospect workings and pits near Jeanty, although only 7 of the larger tunnels and shafts were examined.

The Jeanty workings (No. 8) consist principally of two small tunnels, which expose three or four of the larger veins and some minor fractures. The larger tunnel, east of the ravine, is 40 to 45 meters in length. This tunnel cuts three principal veins, striking N. 70° W., N. 80° W., and about N. 75° E., respectively. None of the veins shows a persistent mineralization. The vein nearest the face of the tunnel strikes approximately N. 80° W., dips about 65° N., and ranges in width from 10 to 40 centimeters. The movement along this vein has brecciated the primary minerals and has formed a gray gouge. The faulting at this fracture appears to be of the normal type. The gouge completely coats some pieces of the brecciated primary vein material. The ore consists principally of chalcopyrite, which is in part altered to limonite and malachite, and some specularite in a gangue of calcite and quartz. This vein is the most promising one seen, but the mineralization is not continuous.

The small tunnel at Jeanty was run along an east-west vein, which widens in places to about 30 centimeters but is practically barren except for some minor stains of malachite.

At Saintival (No. 9) the tunnel intersects a prominent fracture zone that is exposed at the surface. A wide zone of shearing containing abundant clayey gouge is exposed near the face of the tunnel, but it shows little or no mineralization.

Above the Jeanty workings, on the crest of the ridge, a shaft and several small pits were sunk on the northwest-southeast vein. This vein, which follows the crest of the ridge, consists of quartz and a small amount of chalcopyrite.

Across the next ravine to the east a small tunnel (Yadé, No. 10) was run on a fracture striking N. 80° W., possibly a continuation of the more prominent northwest vein on the ridge at Jeanty. Except for a few small lenses showing a stain of malachite the fracture shows no mineralization.

Tenor.—The ore in the fissures at Jeanty appears to be very erratically distributed; some fractures are entirely barren, and large sections of the mineralized veins are also barren. The mineralization appears in small lenses or bunches, which are fractured and faulted. Much movement along these veins occurred after the primary mineralization, and the results perhaps give a false idea of the size and persistency of the original veins

A sample was taken from the vein that strikes N. 80° W. in the larger Jeanty tunnel, as this vein appears to have the richest mineralization. The vein where sampled is 20 centimeters wide and the vein material is in the gouge, entirely free from the walls. This sample, when assayed by Ledoux & Co., of New York, showed copper 5.99 per cent, silver 0.10 ounce, and gold 0.005 ounce per ton of 2,000 pounds. The vein has not been enriched and contains little silver and gold.

Reports mention a pocket on the principal northwest vein, near Ravine Jeanty, which was 2.5 meters wide and assayed about 4 per cent of copper. Other assays show somewhat higher results, the copper running from 8 to 10 per cent, silver 1 to 3 ounces, and gold up to 0.27 ounce.[1]

Mineralogy.—The metallic minerals found in the Jeanty veins are chalcopyrite, specularite, and some pyrite. The gangue is quartz and calcite. The texture of the vein material and the large plates of specularite suggest that the veins were formed at least at moderately high temperatures.

Some oxidation has occurred, especially in the brecciated veins, where the chalcopyrite is partly altered to limonite and malachite. No evidences of chalcocitization were found. The lack of sulphide enrichment is due possibly to the probable greater depth of ground-water level at this locality than at Rocher during Quaternary time, and possibly in part to the texture of the veins. Some slight enrichment may have occurred at deeper levels.

Alteration of the country rock.—The country rock of the veins consists principally of altered quartz diorite porphyries and aplites. These rocks as a whole were considerably metamorphosed during the period of intrusive activity. The principal alterations were widespread albitization of the plagioclase and recrystallization of the primary hornblende. The more altered rocks are seamed with veinlets of quartz and orthoclase and of actinolitic hornblende. The albitized plagioclase has been replaced in part by calcite and epidote. Sericite has been formed in some of the rocks. Shreds of recrystallized uralitic hornblende and granules of titanite are abundant in all the altered porphyries. The alteration appears to have been due to solutions that permeated the rocks during the period of intrusion rather than to the later vein-forming solutions.

Veins at Dolan.

Character and distribution.—The copper veins at Dolan contain metallic copper, cuprite, and chrysocolla, minerals that are not generally found at other places in this district. Although a large number of mineral occurrences are reported in the vicinity of Dolan, the more notable prospects are on two spur ridges of volcanic rock that extend southwestward into the valley from the higher limestone slopes of the mountain.

[1] Ferguson, E. G. W., The mineral resources of Haiti, West Indies: The Mining World, vol. 31, p. 134, July 10, 1909.

Prospects.—The Estime prospect (No. 16 on map), which is the only one at Dolan that has any considerable showing of copper, consists at the surface of strippings and trenchings to the depth of 1 or 2 meters for a distance of about 40 meters along the hillside. The stripping exposes an east-west shear zone, along which the rock is mineralized in places for a width of about a meter. Cuprite is the principal mineral, but pieces of metallic copper as much as 20 centimeters in diameter have been found along this vein. Chrysocolla, malachite, and azurite are also found. The country rock here is pyroxene andesite.

A branching tunnel about 22 meters in length has been driven below the outcrop into the hillside, which slopes about 30°. It apparently penetrates the east-west vein underground, but here the vein is barren and contains much clayey gouge. A similar north-south vein, dipping 40° to 45° W., shows a slight mineralization like that in the east-west vein. The hanging wall of this vein has been locally impregnated and is separated from a breccia in the footwall by a seam of red clay gouge. The exposures in the tunnel show that the mineralization is very erratic and furnish little encouragement for further development.

A number of other small pits and tunnels have been driven on fractures in and around Dolan, but none of them show more than a stain of malachite.

Character and origin of the mineralization.—The veins at Dolan are apparently the result of oxidation of some primary sulphide veins by descending cold solutions. The chrysocolla appears to have been the first mineral deposited and to have been replaced first by cuprite and native copper and finally by malachite and azurite. The chryscolla penetrated the adjacent wall rock more freely than the later cuprite, and, with some of the quartz, it replaces the groundmass of the pyroxene andesite that lies adjacent to the vein walls. The later malachite and azurite have followed the chrysocolla in impregnating the wall rock.

The zone of primary mineralization at Dolan has been completely destroyed, and the present outcrops are now well within the zone of oxidation. The work done on the veins affords no indication that the oxidized minerals overlie a zone of chalcocite enrichment. At slightly deeper levels, however, this oxidized material probably overlies at least a thin zone of chalcocite ore.

The cuprite and native copper found in these veins at Dolan may represent a horizon at or slightly above the ground-water level that prevailed while the chalcocite was being formed in the veins at Rocher. The outcrop of the vein at Dolan stands about 700 meters above sea level, or about 200 meters higher than the outcrops at Rocher.

VEINS EAST OF TERRE-NEUVE VILLAGE.

East and northeast of Terre-Neuve village there are a number of fractures in the andesitic country rock that are slightly mineralized with

copper sulphides and carbonates. The fractures all strike about N. 60°–70° W., and dip 60°–65° NE. Several of the prospects seem to lie along the same fracture zone. At most of the prospects the mineralization is rather scanty and consists of a little bornite and chalcocite and stains of malachite in a gangue of quartz. At several of the pits malachite was the only visible metallic mineral. The country rock is largely fine-grained purplish or reddish andesite, although a few small stocks appear to be intrusive porphyry. In all there are five principal prospects—Justin (No. 17), Reserve (No. 18), Charlestin (No. 19), Edmund (No. 20), and Caille Brulée (No. 21). These prospects are developed by small shafts and tunnels, which seem to have encountered only traces of ore and which give little encouragement for further development.

GENERAL CONCLUSIONS AS TO VEINS.

Considerable work has been done in prospecting the veins in the Terre-Neuve district, and there seems to be enough evidence to warrant the conclusion that none of the veins are of present commercial value.

The enriched veins at Rocher, in which the tenor is rather high, are thin, or they are mere seams, and they would not warrant the outlay necessary to prospect or develop them. There is nothing to encourage the belief that these small seams will coalesce below to form veins of commercial value or that the enriched zones will extend to great depths. The silver, which constitutes the principal valuable mineral in these veins, would naturally be confined largely to the upper part of the chalcocite zone.

The larger and more persistent veins at Ravine Jeanty are only sporadically mineralized, and on the whole even the richer pockets contain only a moderate percentage of copper and little silver and gold. These veins are not enriched.

COPPER BEARING VEINS IN PRE-TERTIARY ROCKS.

By Wilbur S. Burbank and John S. Brown.

General Features and Origin.

Copper-bearing quartz and calcite veins carrying sulphides and iron oxides are widespread in the pre-Tertiary basement rocks in the northern part of the Republic. These veins are of late Mesozoic age and are genetically related to the regional intrusion of quartz diorite of that age. The veins are found in the intrusive rocks and in the old metamorphosed volcanic rocks and associated schists. Most of them are small but some attain widths of 40 centimeters or more. In the country rocks there are shear zones which are in places silicified and cemented by quartz for a width of several meters and which here and there contain sulphides. Large barren quartz veins were seen at a few places in the quartz diorite.

The most common association of minerals appears to be specularite, pyrite, chalcopyrite, and quartz. Many of the quartz veins contain small amounts of titanite and chlorite. The chalcopyrite in some veins accompanies later calcite. Both specularite and pyrite generally show good crystal development in the quartz. Some of the quartz veins carry pyrite and chalcopyrite but no specularite. It is reported[1] that quartz and calcite veins carrying highly argentiferous galena were found at Grande-Rivière du Nord, although no galena was seen in any veins examined during the reconnaissance.

Veinlets of primary calcite carrying pyrite or chalcopyrite occur in the volcanic rocks, especially in chlorite schist. These veins usually accompany quartz veins, and the calcite invariably appears to be of later origin than the quartz.

Many of the veins appear to have been brecciated and recemented before the chalcopyrite was introduced, the conditions indicating that movements were going on during the period of intrusive activity. Some shear zones in the quartz diorite contain quartz and pyrite but most of them contain little or no chalcopyrite.

Most of the veins occur within a few kilometers of intrusive bodies of quartz diorite or in the quartz diorite itself. The occurrence of primary specularite in some of the veins and their field association with intensely altered rocks indicate that they were formed at relatively high temperatures. Some veins containing specularite exhibit comb structure and contain cavities which indicate that they were formed by the filling of open spaces. Many of the veins, however, contain only pyrite and chalcopyrite and a few of them are not near known outcrops of quartz diorite. The alteration of the country rock and the mineral associations of the veins indicate that intrusive contacts are probably near, although possibly concealed.

Thomasset[2] reports that the quartz veins near Grande-Rivière du Nord and Limonade contain considerable quantities of platinum and iridosmium in addition to sulphides and iron oxides, but later investigators have not verified this report, and possibly the samples may have in some way become contaminated. Unfortunately, time was not available during the reconnaissance to permit a careful investigation of these reports.

Thomasset[3] also reports that some of the quartz veins carry free gold, but it probably occurs in quantities so small that its value is negligible. None of the veins have been exploited for gold.

Enrichment of Primary Veins.

The lean primary veins have been somewhat enriched by downward leaching and redeposition, but the enrichment appears to have appreciably

[1] Thomasset, Henri, Notice sur les mines de cuivre de la Grande-Rivière du Nord: Le Moniteur, No. 45, p. 409, Port-au-Prince, 4 juin, 1904.
[2] Op. cit., pp. 408-409.
[3] Op. cit., p. 409.

affected the tenor of the veins only near Grande-Rivière du Nord. The enrichment, which is due to descending surface water, is of the ordinary type found in copper veins and has not only concentrated the copper but also to some extent, the silver. The secondary minerals are bornite, chalcocite, covellite, malachite, and azurite. This enrichment encouraged an attempt to exploit the veins near Grande-Rivière du Nord.

At other places there are small amounts of chalcocite but not enough to enrich the primary vein appreciably. The limonite and copper carbonates found near the surface were formed by the partial oxidation of the pyrite and chalcopyrite.

Tenor of Veins and General Conditions.

The lean primary veins at every locality examined are too small or too low in tenor to be exploitable. Their copper content is low, and they contain only traces of gold or silver.

The enriched veins offer but little more encouragement to prospectors than the primary veins. Attempts to exploit the most promising veins at Grande-Rivière du Nord have been unsuccessful. The primary veins were so very poor and have been so slightly enriched that they hold little promise of yielding ore in commercial quantities. Good evidence of considerable silver enrichment, which seems to be lacking, would be necessary to warrant attempts to exploit any of these veins. The veins are very small and probably do not extend to great depths. Veins containing considerable galena as a primary mineral might contain more silver and show corresponding greater enrichment.

General Distribution.

Veins of the types just described may be found at many places in the northern part of the Republic, where the surface formations are of pre-Tertiary age. (See geologic map, Pl. I.) The veins, however, are more abundant in the Mesozoic volcanic rocks that border intrusive contacts of the quartz diorite. Areas of the intrusive rock itself appear to be less favorable, except near their borders. No promising mineralized veins have been found in the argillites and sandstones of supposed lower or middle Cretaceous age. In general these rocks were probably too near the surface to be strongly altered or mineralized at the time of the intrusion. A large barren quartz vein was seen in the argillites near the crest of the first ridge north of Cerca-la-Source on the trail to Lamielle.

Copper veins occur in many areas that could not be visited during the reconnaissance, but most of the more promising ones were visited.

Copper Veins Near Grande-Rivière du Nord.

LOCATION AND ACCESS.

The copper-bearing veins near the town of Grande-Rivière du Nord have received considerable attention from prospectors. Figure 29, a map of the region around Grande-Rivière, shows the general geologic features and the approximate location of several of the more important prospects.

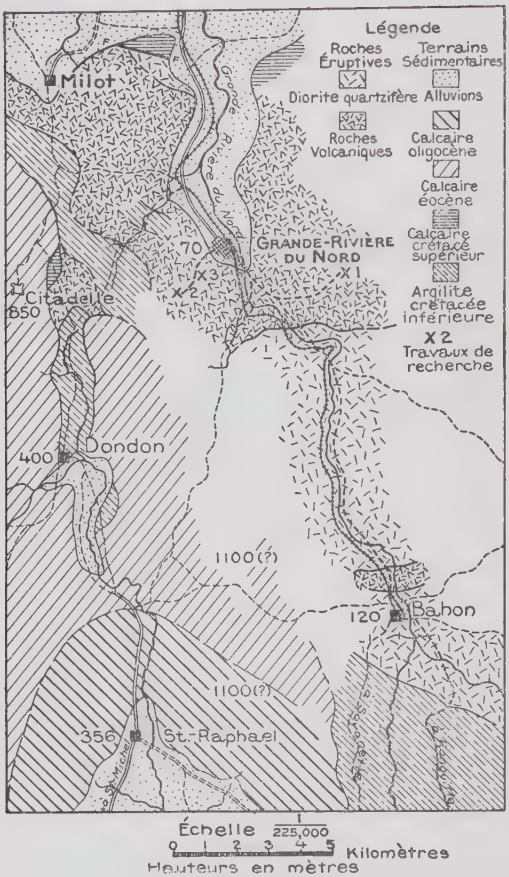


Figure 29.—Geologic sketch map of the vicinity of Grande-Rivière du Nord showing the location of the larger copper prospects.

The town itself is accessible from Cap-Haïtien both by railroad and improved road. The railroad extends up the river valley as far as Bahon, a total distance of 39 kilometers from Cap-Haïtien. The prospects, not all of which are shown on the map, are accessible from the river valley only by horse trails, many of which are very poor. Copper ore has been taken to Grande-Rivière du Nord on pack animals and shipped to Cap-Haïtien by railroad.

The surface rocks in the mountains consist principally of metamorphosed volcanic rocks, which are intricately dissected. The low mountains east and west of the town of Grande-Rivière rise 400 or 500 meters above sea level. The lower ridges or spurs, which extend to the sides of the river valley, stand at altitudes of less than 300 meters. The prospects at Zepiny are at an altitude of 190 meters, about 120 meters above the town of Grande-Rivière. The ridge to the north of the prospects at Zepiny rises to an altitude of 250 to 260 meters.

GEOLOGY.

The rocks of immediate interest in the consideration of the copper veins are altered volcanic rocks, which are probably of middle Mesozoic age, and the intrusive quartz diorite, probably of late Cretaceous age. The volcanic rocks are greenish to reddish much-altered lavas, consisting principally of basalts and andesites. These rocks and the quartz diorite are fully described under the heading "Igneous rocks."

The argillites overlie the older volcanic rocks but are probably intruded by the quartz diorite. This igneous and metamorphic complex is overlain unconformably by limestones of late upper Cretaceous and Tertiary age.

Areas in which the Tertiary limestones are the surface rocks in this locality are, naturally, unfavorable for the occurrence of copper veins, and the areas of altered volcanic rocks appear to be the most favorable. Veins may also be found in the quartz diorite near the borders of the intrusion. No veins were seen in the argillite in this region.

HISTORY OF DEVELOPMENT.

These veins, although probably known much earlier, first received serious attention in 1901, when they were examined by Henri Thomasset.[1] He obtained a concession for the district on July 26, 1901, and began prospecting on January 31, 1902. In his rather optimistic report in the Moniteur he states that in February, 1904, the total length of pits and galleries in hard rock was 290 meters (950 feet).

The work done since 1904 has apparently been intermittent and no records of it are available. According to local reports, work at Cormiers was stopped about 1915. At that time about 10 men were employed. Work at Zepiny was apparently stopped somewhat earlier, in 1913 or 1914. The inhabitants report that at times about 100 men were employed at Zepiny. Although many of the workings were flooded with water when visited and an estimate of the amount of work could not be made, it appears that the larger part of the development must have been done prior to 1904.

[1] Op. cit., pp. 408-409.

VEINS AT HABITATION ZEPINY.

Habitation Zepiny is about 5 or 6 kilometers by trail southeast of Grande-Rivière. (See Fig. 29, No. 1.) The prospects are on both the north and south sides of the eastward trending ravine up which the trail leads from the main river valley. North of the ravine there are two tunnels, and an inclined shaft sunk in part along the intersection of two fractures. One of the fractures strikes about N. 50° E. and dips 70° NW., and a later one strikes north and dips 75° E. The principal mineralization is found along the earlier fracture and in the wall rock for a meter or so from the west wall.

The country rock is a reddish or purplish altered volcanic rock consisting near the vein largely of cemented breccia replaced here and there by quartz and albite and by some chlorite and potash feldspar. The rock is colored red by ferric oxide.

The richer ore in the veins is apparently of secondary origin, having been formed by concentration from downward circulating meteoric waters. It consists of bornite and chalcocite that are in part replaced by copper carbonates in the oxidized zone. The sulphides form veins along joint planes and impregnate the wall rock near the fissures. The brecciated wall rock contains a few sulphide veinlets, 5 to 10 millimeters wide.

Polished sections show that the ore minerals are bornite, chalcocite, and covellite. They cut the primary calcite and inclose primary quartz and specularite. The specularite and especially the calcite were apparently corroded during the secondary mineralization. Most of the specimens were taken in the oxidized zone, within 5 or 6 meters of the surface, and contain no primary sulphides, but a few showed traces of primary chalcopyrite, which, with calcite, had filled small spaces between the quartz crystals.

The veins south of the ravine contain primary quartz and subordinate amounts of calcite and supergene sulphides. They lie along a series of fractures that strike N. 10°–15° E. One of the larger veins is in places about 0.3 meter wide, and the later calcite stringers range in width from mere films up to 1 centimeter. The sulphides generally lie along stringers of calcite and consist principally of chalcocite and covellite. The veins south of the ravine contain less secondary sulphide than those north of it. The quartz is largely barren. Several small shafts have been sunk on these veins, and one on the larger vein is 12 to 15 meters deep.

VEINS IN SECTION CORMIERS.

Prospecting has been done on several veins west of the Grande Rivière du Nord in Section Cormiers. About a kilometer west of the town (No. 3) two branching tunnels have been driven for 20 to 25 meters into a silicified zone in chlorite schist and altered volcanic rock. (For description of the chlorite schist see p. 309.) The metallic minerals are

pyrite and chalcopyrite in quartz and some calcite. Only traces of secondary sulphides were seen. The silicified breccia zone at this locality is at some places 5 or 6 meters wide, but the mineralization is very scanty. The sulphides were developed more freely along clayey gouge in the fractures. The lower tunnel was filled with water when the prospects were visited and could not be explored.

Farther southwest, at habitation La Selle, in the same rural section (No. 2), there are veins of nearly solid chalcocite in altered amygdaloidal basalt. (See p. 270.) Most of these veins are only a few millimeters wide, but at some places they impregnate the country rock in a brecciated zone so as to form small bunches of moderately rich ore. One vein, although it varies considerably, contains at one place a mass of solid chalcocite and malachite ore 5 or 6 centimeters wide.

Sections of the chalcocite ore show that it contains primary quartz, pyrite, and specularite and secondary bornite, chalcocite, covellite, malachite, and azurite. The primary copper mineral in these veins is not known, but float of quartz veins containing pyrite and chalcopyrite was seen on the hillside. Thomasset reports that cuprite was noted in the gossan of some of the veins.

GENERAL CONCLUSIONS AS TO COPPER-BEARING VEINS.

Assays of sulphide ore from Grande-Rivière du Nord are reported to contain at some places as much as 40 or 50 per cent of copper and 3 or 4 ounces of silver per ton, and traces of gold.[1] An examination of the veins shows clearly that the samples giving very high returns were picked samples of copper minerals, most of them taken probably from the chalcocite veins. Although there are small bodies containing high-grade copper ore and small amounts of silver they are too small and scattered to mine profitably.

A sample from a vein of solid chalcocite and malachite ore at Cormiers, about 3 centimeters wide, was assayed by Ledoux & Co., of New York, and gave the following results:

Assay of chalcocite ore from Cormiers, Grande-Rivière du Nord.

Copper	per cent.	64.38
Silver	ounces per ton of 2,000 pounds avoirdupois.	4.50
Gold	ounce per ton of 2,000 pounds avoirdupois.	0.01

The content of silver is low for secondary sulphide ore, indicating a lack of much silver in the primary ore.

The veins give little promise of great persistency, because they are small and because the country rock is faulted and brecciated. The chalcocitization may at some places extend laterally into the country rock for a

[1] Thomasset, Henri, op. cit., pp. 408, 409.

few centimeters or it may occur in small breccia zones, but it is generally so slight that it forms only small bodies of moderately rich ore. In following little seams of doubtful value much barren rock must be mined.

Other Localities.

SECTION LAS LOMAS.

About 6 kilometers northeast of St.-Michel de l'Atalaye, in Section Las Lomas, there are evidences of old mining operations, which are said to have been carried on by the Spaniards in search of gold. A stream near by is called l'Eau d'Or. This place is about 2 kilometers north of the plantation of the United West Indies Corporation, east of St.-Michel. A stream gap in the low limestone mountains on the north side of the Central Plain gives access to a small circular valley floored with volcanic rocks. A low hill at the north end of this valley, about a kilometer north of the gap, consists of metamorphosed volcanic rocks and chlorite schist. A number of veins of quartz containing some calcite carrying small amounts of pyrite and chalcopyrite crop out on this hill.

Besides the old workings, which have entirely caved in and have become grown over with trees, there is a vertical shaft about 15 meters deep and an inclined shaft about 30 meters long, which flattens out to two drifts below. These shafts were sunk on the same vein, which strikes about N. 60° W. and dips rather steeply to the northeast. According to the reports they were driven by an engineer who had been working at one time for the operators at Terre-Neuve.

The principal vein, which is at some places 30 to 50 centimeters wide, consists of quartz and some calcite and carries small amounts of pyrite and chalcopyrite. No secondary sulphides were seen and malachite and azurite are the principal alteration products of the primary sulphides. Veins of calcite and quartz carrying pyrite and chalcopyrite were seen in the chlorite schist on the east slope of the hill. The country rock at these prospects consists of altered amygdaloidal basaltic rocks, chlorite schist, and epidosite. Farther south, along the valley floor, float of partly serpentinized augite peridotite was found. Petrographic descriptions of these rocks are given on pages 287-288, and 309. The intense alteration of the rocks and the formation of the veins of quartz and calcite were probably the result of the regional metamorphism that attended the intrusions of quartz diorite. No outcrops of this rock were seen, but intrusive bodies may be concealed beneath the surface or may crop out farther north.

The veins are evidently not exploitable for copper ore and appear to contain no gold. Significantly large dumps of barren quartz and altered country rock lie near each shaft. Small piles of low-grade copper ore were also seen. The futility of attempting to exploit these lean primary veins is well illustrated by these workings.

PLAISANCE AND VICINITY.

Innumerable small quartz veins carrying sulphides and iron oxides cut the pre-Tertiary volcanic and intrusive rocks near Plaisance and Ennery. They fill small fissures and shear zones, and are generally not more than a few centimeters wide, but at places they attain a width of 5 or 6 centimeters. The primary minerals are specularite, pyrite, and chalcopyrite. Many of the veins are stained with secondary copper carbonates and limonite. Near intrusive contacts veins carrying only quartz and epidote are found.

The country rock of the veins consists largely of much-metamorphosed volcanic rocks, which were partly converted into amphibolites during the batholithic intrusion of quartz diorite. No veins were seen in the argillites of Cretaceous age.

None of the veins examined are large enough or rich enough to be of any commercial interest, and so far as known no attempts have been made to prospect them.

LIMONADE AND VICINITY.

Some copper-bearing quartz veins are found in the mountains that border the North Plain south of Limonade and in the low foothills and exposures of bedrock that crop out through the alluvial deposits of the plain to the north and northeast. The mountains south of Limonade are low spurs that apparently consist of metamorphic volcanic rocks, which extend northward into the plain from the main mass of the Massif du Nord to the south. According to Thomasset[1] and to local reports quartz veins containing copper sulphides, iron oxides, and some platinum and iridosmium are found in these mountains. This locality was not visited during the reconnaissance. Although the presence of copper-bearing quartz veins would be expected in the altered volcanic rocks adjoining the intrusive mass of quartz diorite to the south, the presence of platinum and iridosmium in workable quantities is doubtful. The reports concerning these deposits like those concerning deposits at Grande-Rivière du Nord, have not been confirmed.

At Morne Beckly, a low hill of pre-Tertiary schists and metamorphosed volcanic rocks about 6 kilometers east of Limonade, there are veins of quartz and chalcopyrite, which contain limonite and malachite as oxidation products. Farther east, near Le Trou, float of similar vein filling was found. These veins did not contain much primary iron oxide. Veins of quartz containing specularite and magnetite and in places epidote are described on pp. 468-469. These veins apparently are distinct from the copper veins.

JEAN RABEL.

About 8 kilometers southwest of Jean Rabel some mineralization is found in the quartz diorite and granodiorite porphyries of Cretaceous age.

[1] Thomasset, Henri, op. cit., p. 409.

At the locality visited a small pit has been dug and a tunnel face started for a meter or two on a mineralized fracture containing quartz, chalcopyrite, and molybdenite. Both the chalcopyrite and molybdenite impregnate the brecciated quartz diorite porphyry to a slight extent near the fracture. Except for stains of malachite and limonite there are no secondary minerals and no signs of chalcocitization. These mineralized fractures are of no economic value. This is the only place where molybdenite was seen in the copper veins. The presence of this mineral probably indicates that the vein was formed at a relatively high temperature.

Altogether possibly 8 or 10 square kilometers of intrusive porphyries are exposed in this locality. Many of the porphyries are impregnated with pyrite and considerably altered. (See p. 295.) The conditions at this place do not seem to be particularly favorable for the discovery of valuable mineral deposits. The porphyries are overlain unconformably by the upper Eocene limestone, and boulders of the igneous rocks are abundant in the basal conglomerate of this formation.

IRON DEPOSITS AT MORNE BECKLY.

By Wilbur S. Burbank and John S. Brown.

Geography and Geology.

Morne Beckly lies about 5 kilometers east of Limonade, on the main road between Cap-Haïtien and Ouanaminthe. It is a low, dome-shaped swell, roughly 400 or 500 meters in diameter, standing about 35 or 40 meters above sea level, 10 meters higher than the surrounding plain. The hill, which is an outcrop of bed rock that projects above the alluvial deposits of the plain, consists largely of talcose, chloritic, and amphibolitic schists. The schistosity strikes about N. 30°–40° W. and dips steeply. The schist is intruded by small dikes of quartz diorite porphyry and felsite and by a number of small pegmatitic veins of quartz. Some of the quartz pegmatites have a pinch-and-swell structure that is characteristic of intrusion during deformation. Veins of quartz and epidote were seen, some of them containing iron oxides. The schists appear to be considerably deformed and are locally contorted and faulted.

The age of these schists is uncertain, but they show a degree of metamorphism greater than that noted at most other places in the Republic. Undoubtedly some deformation took place during or somewhat before the quartz diorite intrusion in Cretaceous time. The schists and intrusive porphyries are more fully described on pages 296, 308-309.

Character and Occurrence of Ore.

The presence of magnetic iron ore on this hill has been known for some time and is mentioned in a number of accounts published during the colonial period. Some prospecting has been done, principally by Henri

Thomasset,[1] who made numerous surface trenches across the hill, but no ore was shipped. He gives four analyses showing only the amount of metallic iron in the samples, which ranged from 61 to 65 per cent.

The iron is found in boulders consisting of magnetite, hematite, and quartz. These boulders may be as much as 30 centimeters in diameter and are strewn apparently irregularly over the surface of the hill. The ore is only a comparatively thin veneer in the residual soil on the ground, and at no place on the hill or in the prospect trenches was there any indication of the primary ore body from which the boulders were concentrated.

Nearly all the ore contains some quartz, and in some blocks a considerable proportion of quartz cements the iron oxides. Sections of the ore show both magnetite and hematite in varying proportions. Some sections showed plates of specularite entirely replaced by magnetite and in turn partly replaced by a second generation of hematite.

Origin.

The mode of origin of the iron oxides is not clearly evident, but they probably owe their formation to the igneous activity that accompanied the intrusion of quartz diorite during Cretaceous time. Dikes of quartz diorite porphyry and felsite cut the schists in the vicinity of the deposits. The field relations indicate that the iron oxides were segregated in the quartz veins that cut the schists. The association of the iron oxides with quartz seems to be general. Although no large veins carrying iron were found, many small quartz veins, 8 to 10 centimeters wide, carrying abundant specularite and magnetite were seen on Morne Beckly, and these minerals occur as float at other places on the North Plain. One large piece of a vein that was 10 to 12 centimeters wide contained 70 to 80 per cent of specularite and magnetite, the remainder of the vein being milky quartz. Smaller veins contain, besides quartz and iron oxides, some iron-rich epidote.

It seems quite certain that if the iron originated in quartz veins there are no large ore bodies and that the iron found on the surface is a residual concentration effected during a long period of erosion. The southern part of the North Plain has apparently been eroded under relatively stable conditions for a long time, as is indicated by concretionary deposits of iron and manganese found on its surface at other places. (See p. 477.) The drainage on the plain is relatively inactive and does not quickly remove the residual products of weathering.

The iron may have been formed by the contact-metamorphism of limestone bodies in the schists, but most of the evidence seems to be against such a hypothesis. No limestone bodies were found in the metamorphic complex on the North Plain, and no characteristic contact minerals are associated with the magnetite and specularite.

[1] Op. cit., p. 409.

Economic Value.

The quantity of iron ore visible on Morne Beckly is insufficient to give the deposits any commercial value. The hill is only 400 to 500 meters in diameter and the soil, which contains only a relatively small percentage of iron ore, is thin. Whether or not commercial ore bodies are concealed in the metamorphic complex here or elsewhere on the North Plain can be determined only by extensive prospecting and magnetic surveying.

An analysis of a boulder consisting principally of magnetite and hematite and a little quartz gave the following results:

Analysis of iron ore from Morne Beckly.

[By Ledoux & Co., New York.]

	Per cent.
Fe	70.75
SiO_2	4.17
P	.011

DEPOSITS OF MANGANESE.

By Wilbur S. Burbank and John S. Brown.

Manganese Deposits in the Commune of Gros-Morne.

GEOGRAPHY AND GENERAL GEOLOGY.

The manganese deposits here described are about 20 kilometers by road northeast of Gonaïves, in the Commune of Gros-Morne, just west of the Gonaïves-Gros-Morne road. They lie 300 to 350 meters above sea level, on a series of broken ridges that trend about N. 30° W. (See Pl. II, in pocket, prospects Nos. 22 and 23.) The largest deposit seen is on one of the most prominent of these ridges, called Morne Macat, which stands 200 to 300 meters west of the road and rises 140 to 150 meters above the level of the road. The road is easily passable for automobiles as far as the deposits.

The geology of the region is shown on Plate II. The ridge of Morne Macat is a fault scarp marking the contact between the downfaulted upper Oligocene limestone that lies east of the ridge and the basal upper Eocene and the Mesozoic volcanic rocks that form the main mass of the ridge and the country rock for several kilometers to the west. The volcanic rocks are overlain by basal upper Eocene conglomerate and limestone, which form the crest and part of the slope of the hill and dip 30° to 50° E. The upper Oligocene limestone east of the fault is sharply upturned and dips about 65° E.

Along the fault plane between the sedimentary and the igneous rocks considerable jasper, chalcedonic silica, and quartz were deposited, forming lens-like veins from 3 to 5 meters wide. The manganese is concentrated in these veins.

CHARACTER AND EXTENT OF FAULTING.

The fault is apparently normal. The fault plane is at most places nearly vertical but at some places dips steeply eastward. The strike of the plane at this locality is about N. 30°–40° W. The throw of the fault corresponds approximately to the thickness of at least the basal part of the Eocene limestone in this region, which is probably at least 500 meters, possibly much more. Figure 30 gives sections across the mountain at Morne Macat and shows the relation of the deposits to the limestones and the volcanic rocks.

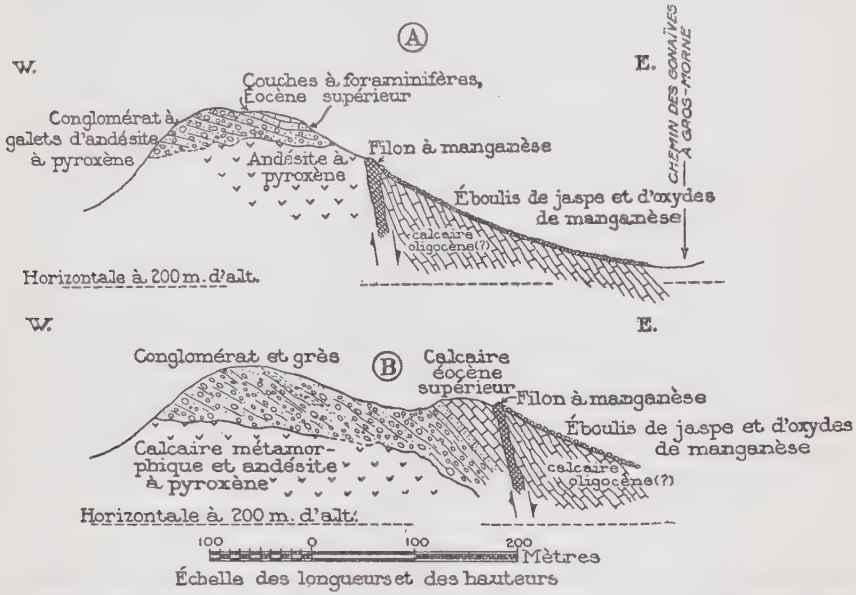


FIGURE 30.—Sections showing the manganese deposits in the Commune of Gros-Morne.

A, outcrop 22; *B*, outcrop 23. For locations see Pl. II (in pocket).

A complete description of the northward and southward extensions of this fault is given on pages 120-121.

MINERALOGY.

The manganese minerals found in these deposits are oxides, generally in intimate mixtures. Judged by their physical properties and by other simple tests the more common minerals are probably manganite ($Mn_2O_3.H_2O$), pyrolusite (MnO_2), and wad, but they can not be accurately identified without chemical analysis. No silicates or carbonates of manganese were found. The mineral aggregates vary from soft masses to hard crystalline or amorphous looking lumps, some of which are in the form of botryoidal and fibrous growths. The deposits may contain psilomelane

and other minerals but none were identified, either by their physical character or by chemical tests. Most of the aggregates of manganese minerals are either intimately intergrown or veined with siliceous material that consists of quartz, chalcedony, and jasper.

Thin sections of the ore show that at many places the manganese and silica must have been deposited nearly contemporaneously. In some of the sections the manganese oxides are clearly earlier in origin than the quartz and chalcedony; in others they are in part later. A section of richer ore shows that manganese was deposited with earlier fine-grained quartz and chalcedony. These minerals were followed and usually surrounded by coarser radial or spherulitic growths of chalcedony, and finally by granular and prismatic quartz. Later quartz and chalcedony veinlets cut all the structures and carry some fibrous growths of manganese. The later generations of chalcedony and quartz are clearer and less stained by the iron and manganese oxides.

Sections of ferruginous and manganiferous jasper show that the original jasper has been in part replaced by manganese oxides. Some of the jasper is stained brilliant red, yellow, and dull brown from admixture of iron oxides; some of it is green, but the exact cause of this color is unknown; some of it is stained black by manganese oxides and is veined with small stringers of manganese oxide, usually consisting of pyrolusite. The greater part of this deposit, however, consists of ferruginous jasper, which is reddish or yellowish brown in reflected light and nearly opaque to transmitted light. It appears to have been partly recrystallized, though it may have originally contained some spherulitic growths of quartz that have a zonal staining. The later manganese oxides have usually replaced the jasper between the quartz spherulites. Later veins of quartz and chalcedony cut across both the jasper and the manganese oxides and replace some of the former structures.

At many places the ferruginous jasper evidently replaces the limestone wall rocks, as it contains fossils. At several places the limestone is silicified and shows a fine crystalline intergrowth of quartz and chalcedony, which preserves the bedding laminations. In some thin sections the limestone has evidently been directly replaced by manganese oxides.

The andesites that form the west wall of the fault zone are less extensively silicified than the limestone. In some andesite near the fault zone the augite and the feldspars have been brecciated and replaced by calcite. The alteration of the andesite is generally accompanied by a change of its original greenish color to brown or light gray.

A study of thin sections of the ore shows that the manganese either accompanied silica introduced later into the jasper or was concentrated during a secondary silicification or crystallization from manganese originally disseminated through the jasper. The manganese oxides do not appear to have replaced earlier silicates or carbonates, and their intimate association with the chalcedony and quartz shows that the oxides were

deposited with the silica that crystallized later. If the manganese was originally deposited in some other form than as oxide some of the original jasper or silica was taken into solution during the oxidation of the vein and redeposited as quartz and chalcedony with the oxides. It seems more probable, however, that the manganese was originally deposited as oxide disseminated through the jasper, both probably having been in places deposited as colloidal gels, and that later redistribution and recrystallization in the jasper caused the local concentration of the manganese oxides and the formation of later generations of chalcedony and quartz. The crystallization of gelatinous silica to chalcedony and quartz could have been caused by a rise in the temperature of the depositing solutions.[1] Some of the manganese oxides at the surface, however, were undoubtedly redeposited by surface waters, for small seams of pyrolusite associated with later calcite, soft masses of wad, and surface breccias formed by the cementing of jasper fragments by iron and manganese oxides can be positively attributed to the action of surface water.

The mineralogy and the texture of these ores are very similar to those of some of the "bayate" deposits of the Island of Cuba.[2] They differ to some extent, however, in their mode of occurrence, in that the Cuban deposits are not associated with definite fault zones but are replacements of limestones and tuffaceous sediments, usually along bedding planes. The ores of the Haitian and Cuban deposits are probably also similar chemically, although the Haitian ore analyzed (see p. 475) is more siliceous than the better grade Cuban ore. Small amounts of barium and copper were also found in the Cuban ores.[3]

ORIGIN OF THE DEPOSITS.

These deposits were probably formed in one of three ways—(1) by deposition from cold descending meteoric waters, which leached their mineral content from the overlying limestone or igneous rock; (2) by deposition from ascending hot or cold meteoric waters which, after penetrating to considerable depths, escaped upward along the fault plane, deriving their mineral content from the rocks along which they passed; or (3) by deposition from ascending hot waters of magmatic origin, which derived their mineral content largely from the magma.

The large amount of chalcedony, jasper, and quartz in these deposits indicates that they were formed by hot spring waters that rose along the

[1] For a discussion of the formation of certain jasperoids in the Tintic district, Utah, and for further references to the deposition of gelatinous silica, see Lindgren, W., and Loughlin, G. F., Geology and ore deposits of the Tintic mining district, Utah: U. S. Geol. Survey Prof. Paper 107, pp. 154-159, 1919.

[2] Burchard, E. F., Manganese-ore deposits in Cuba: Am. Inst. Min. and Met. Eng. Trans., vol. 63, pp. 51-104, 1920. Hewett, D. F., and Shannon, E. V., Orientite, a new hydrous silicate of manganese and calcium from Cuba: Am. Jour. Sci., 5th ser., vol. 1, pp. 491-506, 1921.

[3] Burchard, E. F., op. cit., pp. 65 and 83.

fault plane, as descending cold meteoric waters would not carry so much silica. There is little or no evidence to show whether the hot waters were derived from deep seated meteoric circulation or from igneous intrusives, and the period of their activity is not known. The structure competent to provide artesian pressure for the upward circulation of meteoric water along the fault has not existed during Recent time and probably did not exist during Pleistocene time. Possibly, however, structure suitable to give artesian pressure existed during Miocene time, before the greater part of the Eocene and Oligocene limestones in the western part of the Massif du Nord had been removed by erosion. If such a structure existed, the area of intake probably lay northeast of the fault, toward the center of the arch in the western part of the Massif du Nord. (See Pls. I and XXVII.) If there were suitable retaining beds in the basal part of the limestone series, part of the water entering at the intake area might have been confined to the contact between the volcanic rocks and the overlying limestones. Upon reaching the fault the waters would escape upward, and at lower temperature and pressure would probably deposit part of the minerals they leached from the volcanic rocks and the basal beds of the limestone.

It is, however, more probable that the deposits were formed by hot spring waters associated with igneous activity of Miocene or later age and could be correlated with the Miocene intrusion of quartz diorite in the Montagnes de Terre-Neuve. (See pp. 428, 433.)

CONCLUSIONS AS TO CHARACTER OF VEINS.

The bodies containing the manganese are probably discontinuous lens-like veins formed at favorable places by hot spring waters that ascended along the fault zone. Probably they replaced the limestone wall rock and filled and widened open spaces, the proportion in which the two processes combined varying from place to place or from time to time. At many places along the fault there is no vein, although some hydrothermal action is indicated by the bleaching and alteration of the andesitic wall rock. If the vein was not formed by surface oxidation but originated as suggested above the oxides of manganese probably continue below the zone of oxidation.

South of Morne Macat deposits of ferruginous jasper were seen on several small ridges along the line of the fault for a distance of 2 or 3 kilometers but no large quantities of manganese accompanied the jasper. The longest continuous vein exposed is the vein on the east slope of Morne Macat, which is 3 to 5 meters wide and at least 160 to 170 meters long. Of this entire exposure only about 20 meters midway on the hill, where the vein is 8 or 9 meters wide, has any appearance of containing sufficient manganese to be of commercial interest. A chip sample taken across the entire width of this ore body was analyzed in the chemical laboratory

of the United States Geological Survey by J. G. Fairchild and the analysis gave the following results:

Partial analysis of manganese ore from Morne Macat.

	Per cent.
Mn	25.8
Fe_2O_3	1.52
P	.028

In the course of the analysis the presence of what is probably barium was found. A little copper was identified.

As the gangue of the manganese oxides is almost entirely siliceous, probably 40 to 50 per cent of the ore analyzed is silica. Ore containing so much silica is not commercially valuable. Although the silica content of the ore might be reduced by sorting, much of the manganese oxide is so intimately mixed with the siliceous gangue that even mechanical concentration would be expensive. The lumps of pure manganese oxides are not usually large enough to be successfully hand sorted. A few small veins and masses of pure manganese oxides, 8 to 10 centimeters in width, were seen, but most of the manganese is mixed with the jasper. A large quantity of float is found on the hillside below the jasper reef, out of which lumps of high-grade manganese ore can be picked, but the percentage of lumps of high-grade ore is low. There is not enough manganese at this locality to warrant the exploitation of the deposit at the present price of manganese, but there is enough to suggest that if the price should again rise careful prospecting here as well as along the entire length of this fault zone would be warranted.

No other bodies of manganese ore were found but others may exist along the fault zone. Slight silicification of the limestone, forming limonitic jasper, bearing some stains, probably of manganese, was seen along the same fault line at Rivière Lhormand, about 5 kilometers west of Gros-Morne. (See pp. 120-121.)

Manganese Deposits in the Commune of Jacmel near Coteaux.

Manganese deposits are reported to occur at several places in the mountains north of Jacmel, in the drainage area of the Grande Rivière de Jacmel and its tributaries. One small deposit that was examined during the reconnaissance is about 12 kilometers north of Jacmel, near the habitation called Coteaux. It is along a fault contact between the basal upper Eocene limestone and the basaltic volcanic rocks of late Cretaceous age. The structural conditions here are remarkably similar to those at the Morne Macat deposits, near Gros-Morne. The strike of the fault is nearly parallel to the strike of the limestone, about N. 60° W. The dip of the contact plane between the limestone and the basalt could not be determined but was probably very steep. The

limestone, which forms the south wall of the contact, is sharply upturned and dips 80° to 90° southward. It is dark gray to black, thin bedded, and contains numerous small Foraminifera, which are replaced by chalcedony and opal near the fault zone. For several hundred meters south of the fault the limestone is dark and thin bedded and the dip gradually decreases until, about half a kilometer down the river, it is reversed.

The structure of the basalt flows that form the country rock north of the fault can not be definitely determined, but as they were folded with the Eocene limestone they probably also dip southward. About half a kilometer north of the fault a band of metamorphic limestone underlies the basalt. (See Fig. 20, *B*, p. 322.)

Along the fault plane masses of ferruginous jasper and quartz similar to those at Morne Macat have been deposited. Near the river this zone of jasper is 9 or 10 meters wide but it appears to pinch out east of the valley. Much float of ferruginous chert and some manganese oxides, mostly pyrolusite, was seen in a ravine that joins the river just south of the fault zone. This ravine follows the contact of the limestone and igneous rock for some distance but no other large masses of manganiferous jasper were found in place.

The ferruginous jasper contains hematite and limonite and entirely replaces the limestone, for it incloses fossils. Both jasper and manganese oxides have been brecciated and have been recemented by a secondary silicification, the product consisting largely of granular and prismatic quartz. Considerable calcite and some natrolite were deposited along the fault plane. Much of the quartz was undoubtedly deposited later than the manganese oxides.

These deposits afford no evidence as to the origin of the water that produced them, but they, like those of Morne Macat, were probably formed by hot spring waters that rose along the fault plane. As the major structure in the center of the peninsula north of the fault is that of an anticlinal arch (Fig. 20, *B*), suitable structure may have existed during middle Tertiary time to permit the upward escape along the fault zone of waters under artesian pressure. No traces or other evidence of middle Tertiary volcanic eruptions have been preserved in the Southern Peninsula, though there may have been some igneous activity, deep seated or minor, during Miocene time. (See p. 320.) Hot spring waters issuing from fissures in basaltic rocks at the Sources Chaudes, in the western part of the peninsula, are possibly manifestations of late Tertiary igneous activity. (See pp. 564-566.)

The deposits near Coteaux are of no economic value whatever, as the amount of manganese they contain is negligible. They indicate, however, areas or zones along which prospecting for manganese might be attempted should market conditions warrant the expense. The continuation of the contact between limestone and basalt would be a favorable place for prospecting. Faults or bedding planes that were competent to confine

rising thermal waters appear to mark places favorable for the deposition of manganese-bearing jaspers, but an easily replaceable wall rock, such as limestone, is probably essential to the formation of large ore bodies.

RESIDUAL CONCENTRATIONS OF IRON AND MANGANESE.

By Wilbur S. Burbank and John S. Brown.

General Features.

Residual deposits of iron and less commonly of manganese are found in regions of humid climate where rather basic igneous rocks or impure limestone have long been weathered. During the reconnaissance some residual concretionary deposits of iron and manganese were seen in regions of imperfect drainage. Although no commercially valuable deposits of this kind are known in the Republic, there are numerous deposits of ferruginous clay that have attracted attention and are often reported as "iron ores." Red residual clayey soils are common at many places, both on limestone and igneous rock, and are especially widespread in areas of massive impure limestone, either around sink holes or covering level country. Some of this residual clay makes an excellent agricultural soil, and at a few places, as near Grande-Rivière du Nord, it is used for making building bricks. Where the residual material is colored bright red or yellow by admixture of iron oxide it is sometimes used as a temporary paint on mud walls.

Chemical analyses of concretionary masses of iron and manganese and of iron-rich soils that were collected during the reconnaissance show that the particular deposits sampled do not contain commercial quantities of either iron or manganese. Two ferruginous residual soils, one from basalt and one from limestone, contained about 17 per cent of iron. Concretionary deposits of iron and manganese analyzed contained 3 to 4 per cent of manganese and 15 to 20 per cent of iron. These samples probably represent some of the richer concentrations of these oxides, and the results of the analyses indicate that the deposits are of no value. Small bodies of iron ore of commercial grade may be found, but probably no valuable large bodies.

Iron and Manganese on the North Plain.

The deposits on the North Plain that were examined are on the surface of a flat, slightly dissected savanna that lies 4 or 5 kilometers northeast of Acul Samedi. The plain, which here stands 60 to 80 meters above sea level, is floored with gravel of Quaternary age. The narrow stream valleys are entrenched in the plain deposits to a depth of 5 or 6 meters. The sediments consist largely of gravel and sand derived from the quartz diorite and include some beds of finer silty material. The deposits are lenticular and crossbedded and vary greatly in composition. They are nearly horizontal, parallel to the surface of the plain.

Where the drainage has been inactive the relatively insoluble constituents of these sediments have been left at the surface and the soluble ones have sunk into the porous gravels with the rain water. A typical section down through the gravelly or sandy deposits shows at the surface nodular concretions of iron and manganese oxides partly encrusting pebbles, quartz grains, and other unweathered material, but here and there cementing the sand into a hard mass. Below such a mass at many places there is a layer of reddish to yellowish residual clay, very sticky when wet, containing pebbles, sand, and quartz grains. This layer grades down to less weathered or unweathered gravel.

The iron and manganese oxides form rounded concretionary masses, some of them 10 to 15 centimeters in diameter, most of which contain considerable residual sand and fine gravel. Some of the concretions contain a large proportion of yellowish clay, the included material depending on the nature of the ground in which the concretions were formed. The iron occurs largely as yellowish or brownish limonite. The manganese minerals are brown or black and probably consist of wad and pyrolusite mixed with iron oxides. The concretions form only a very thin veneer, which rarely extends more than a few centimeters below the surface. They are scattered over an area that is probably 6 to 8 kilometers wide, but they contain little iron and occur in quantities so small that they are of no economic value.

Analysis of iron and manganese oxide concretions collected northeast of Acul-Samedi.

[Ledoux & Co., New York, analysts.]

	Per cent.
Fe	15.60
Mn	3.20
SiO_2	60.17
P	.026

The source of the iron and manganese is evidently the hornblende of the quartz diorite. The residual soil on the quartz diorite bedrock is described on pages 297-299.

Iron and Manganese Near Paul.

Iron and manganese oxide concretions appear to be rather widely distributed in the areas of igneous rocks in the Montagnes Noires and were seen near Paul along the trail from St.-Michel de l'Atalaye to Dessalines. About 3 kilometers northeast of Paul, just southwest of the first limestone range that borders the Central Plain, is a large savanna, much of which is underlain by a coarse dacitic porphyry that contains much hornblende. This rock is decomposed by weathering into several products, among them oxides of iron and manganese, which are derived mainly from the ferromagnesian minerals of the rock, hornblende and mica. These oxides, like

those in the deposits near Acul Samedi, become concentrated in the residual soil and form concretionary masses or encrust lumps of gravel, clay, and unweathered material. The iron occurs as brown or yellow limonite, and the manganese probably as wad and pyrolusite.

The oxides are mostly concentrated at the surface, where there are some lumps measuring 10 to 15 centimeters in diameter. An analysis of one of these lumps shows that they are similar to those found at Acul Samedi:

Analysis of iron and manganese oxide concretions collected near Paul.

[Ledoux & Co., New York, analysts.]

	Per cent.
Fe	20.15
Mn	4.40
SiO_2	47.04
P	.176

The deposits are richer in small, flat areas that have not been actively eroded, for on steep slopes or along gullies the products of weathering are washed away. The amount of manganese found more than one-half or at most one meter below the surface is not sufficient to form more than stains in the soil.

The area covered by such patches of residual oxides in the savanna northwest of Paul includes, perhaps, several square kilometers. In the large valley in which the village of Paul is situated float of similar material was seen, but no deposits were found in place.

These deposits, like those on the North Plain, are of no economic value.

Iron in the Southern Peninsula.

By John S. Brown.

Iron ores are reported to occur at several places in the Southern Peninsula, particularly near Anse d'Hainault and in section Plymouth, between Jérémie and Baradères. At both places there is some basis for the reports.

Residual deposits on basaltic rocks near Anse d'Hainault.

About 2 kilometers south of Anse d'Hainault the trail to Tiburon crosses a ridge of basalt that is perhaps a kilometer wide. The basalt has at places weathered to a conspicuous bright red soil that evidently contains considerable iron. A good exposure was found on a sea cliff at the north side of the ridge beside the trail. For 2 or 3 meters below the surface the rock is completely oxidized to red soil. Below that depth traces of the basaltic rock showing pronounced pillow structure are increasingly prominent and the red color is spotted more and more with gray and nearly disappears at a depth of 10 meters. Spheroidal masses of basalt seen here weather in concentric layers that are alternately red and gray. The sample taken for analysis is probably considerably richer in iron

than the rock in most of the oxidized zone. An analysis by Ledoux & Co., New York, of the residual soil on basalt near Anse d'Hainault showed that it contains 17 per cent of iron.

A concentrated deposit of particularly rich red clay containing some hematite was found covering a few square meters on the south slopes of the hill. It was probably concentrated by leaching and by the sorting action of running water.

The area of less oxidized ferruginous soil includes possibly several square kilometers but contains no ore of commercial quality.

Other exposures of basalt that break down into similar red hematite-bearing earth were noted in sea cliffs between Chardonnières and Les Anglais and west of Les Anglais. More promising deposits may perhaps be found in some of the areas of basaltic rocks.

RESIDUAL DEPOSITS ON LIMESTONE BETWEEN JÉRÉMIE AND BARADÈRES.

The other type of deposit also is residual but is found in areas of massive upper Eocene limestone, particularly in the region between Jérémie and Baradères. The limestone breaks down first into a soil that is colored red by ferric oxide. An analysis by Ledoux & Co., New York, of this residual soil on limestone about 10 kilometers west of Baradères showed that it contains 16.80 per cent of iron.

Further action on this soil by percolating water produces here and there lumpy concretions of hard brown limonite or hematite. Most of the lumps are less than 2 centimeters in diameter but some are much larger. A few lumps about 10 centimeters long were seen. Running water frequently washes away the loose red soil and concentrates deposits of little limonite pebbles in the gullies. Such deposits are of no commercial value. It is barely possible that material concentrated as cave breccia in the numerous sink holes might be of better grade.

NONMETALS.

By John S. Brown and Wendell P. Woodring.

LIGNITE.

The Republic of Haiti contains probably the most extensive deposits of lignite in the West Indies proper. The largest potential lignite field is in the northwestern part of the Central Plain near Maïssade, but there are other deposits near Camp Perrin, in the arrondissement of Les Cayes. Beds of impure lignite and carbonaceous clay in the Asile Valley are mentioned on page 229. Beds of black chert in upper Eocene limestone (see p. 134) and pieces of carbonized wood in Miocene beds have led to reports of deposits of lignite. The Miocene deposits are the only ones in the Republic that were laid down under conditions favorable for the accumulation of vegetable débris. Miocene rocks in regions not explored during

the reconnaissance may possibly contain beds of lignite. It is not likely that coal of higher rank than lignite will be found anywhere in the Republic.

Lignite Near Maïssade.

Several accounts of the deposits of lignite in the northwestern part of the Central Plain have been published, but the report by Tippenhauer[1] is the only one that has been examined.

The beds of lignite are confined to the Maïssade tongue of the Thomonde formation. The area containing lignite probably coincides with the area floored by Maïssade rocks, embracing about 100 square kilometers. (See Pl. XXXVI.) This estimate is based on the assumption that the beds of lignite extend across the trough of the Central Plain syncline, where they are concealed by younger beds of the Maïssade tongue. The outcrop of the lignite-bearing beds on the northeast limb of the syncline is also concealed by stream deposits.

The lithology and stratigraphic relations of the Maïssade tongue are discussed on pages 168-173.

Most of the beds of lignite occur in the middle part of the Maïssade tongue, interbedded with sandstone, siltstone, and clay containing a mixture of marine and brackish-water mollusks or only brackish-water mollusks. The lithology and fossils show that these beds were laid down in a coastal swamp. The part of the Maïssade tongue containing lignite was examined on Rivière Frio south of Maïssade, and on Rivière Fond Gras, Rivière Fond Bleu, and Rivière Blanche northwest of Maïssade. At all these localities the beds dip at angles of 45° to 70° northeastward, toward the trough of the Central Plain syncline, which extends northwestward approximately through Maïssade. Farther to the northeast the beds flatten rather abruptly and dip at angles of 2° to 6° toward the trough of the syncline. The beds of lignite were not examined in this region, where they dip gently.

Sections showing the thickness of the beds of lignite are given on pages 170-173. The section on page 173, measured on the right bank of Rivière Frio about 100 meters above the crossing of the road from Maïssade to Hinche, shows two beds of lignite. The lower bed, containing many dirty streaks, is 2.5 meters thick. The upper bed is 1.47 meters thick, but it contains two benches of lignite 14 and 17 centimeters thick, separated by carbonaceous clay. Sample No. 2 of the table of analyses on page 482 was obtained from a channel of uniform width across the entire thickness of the upper bed. Sample No. 1 was obtained from the upper bench of lignite in the upper bed. The section measured on Rivière Fond Gras a short distance above its confluence with Rivière Canot (see p. 172) shows four

[1] Tippenhauer, L. G., Beiträge zur Geologie Haïtis; VI, Das Lignitlager von Maïssade und der Aufsteig zum Zentralplateau von Gonaïves und von Norden aus: Petermanns Mitt., Band 47, pp. 193-199, pls. 15 and 16 (map and sections), 1901.

beds of lignite having a thickness of 9, 67, 93, and 22 centimeters in ascending order. The thick beds contain partings and benches of dirty lignite or carbonaceous clay. A bed of lignite 17 centimeters thick was measured in the section of beds in the lower part of the Maïssade tongue as exposed on Rivière Fond Bleu. Five beds of lignite having a thickness of 5, 54, 75, 125, and 48 centimeters in ascending order are shown in the section on page 171, measured on Rivière Blanche. All the beds contain partings of impure lignite and clay.

Not enough field work was done to determine the number and continuity of the lignite beds. The section on Rivière Blanche, which includes the greater part of the lignite-bearing series, shows five beds. The beds probably are lenticular.

The lignite was examined only on weathered outcrops. Most of it is dark brown and has a woody texture and dull luster, but some of it is black and harder and has a shining luster. The black, shining lignite may occur in lenses in the dull, dark-brown lignite or it may make up entire beds. The surface of the dark-brown lignite shows a network of cracks due to loss of moisture by evaporation. The black lignite shows fewer cracks.

The following table gives the results of analyses of two samples collected on Rivière Frio:

Analyses of lignite from Maïssade.

[Made at the Pittsburgh laboratory of the United States Bureau of Mines; H. M. Cooper, chemist.]

Form of sample analyzed.	Proximate analysis.				Ultimate analysis—sulphur.	Heating value (calories).
	Moisture.	Volatile matter.	Fixed carbon.	Ash.		
Sample 1:						
As received	31.55	29.91	28.79	9.75	3.89	3,737
Air dried	21.50	34.30	33.02	11.18	4.46	4,285
Moisture free	....	43.70	42.06	14.24	5.68	5,459
Moisture and ash free	....	50.96	49.04	....	6.62	6,365
Sample 2:						
As received	26.18	27.55	20.69	25.58	4.15	2,594
Air dried	16.08	31.32	23.52	29.08	4.72	2,949
Moisture free	....	37.32	28.03	34.65	5.62	3,514
Moisture and ash free	....	57.10	42.09	....	8.60	5,377

The samples were taken by cleaning off the weathered surface to a depth of a few centimeters and cutting a channel about 10 centimeters wide and deep across the bed. The material thus obtained was broken into small pieces, quartered, and placed in a can.

As these samples were collected from the outcrop they contain less moisture than samples from underground workings. The loss of moisture is shown by the numerous cracks in the lignite at the outcrop. Sample No. 2, from a channel across the entire bed, includes dirty lignite and

carbonaceous clay, some of which could probably be excluded in mining. The high percentage of ash and low heating value of this sample are due to this incombustible material.

Tippenhauer[1] records the following analysis, but the locality and form of material analyzed are not given:

	Per cent.
Moisture	16.05
Volatile matter	41.30
Fixed carbon	22.65
Ash	20.00
Sulphur	3.19
Heating value in calories	3,829

This analysis represents a picked sample, as the heating value is relatively high. The percentage of moisture is lower and the ratio of fixed carbon to volatile matter is much lower than in the analyses on page 482.

The relative value of the Maïssade lignite is discussed on pages 485-487.

Lignite near Camp Perrin.

It has long been known that lignite beds crop out near Camp Perrin, in the arrondissement of Les Cayes. Eugène Nau[2] published an official report on this lignite in 1859-60, and Thomasset[3] described it in 1898.

The lignite-bearing beds were examined on La Ravine du Sud and on La Rivière. They are of Miocene age and were deposited in lakes, fresh-water swamps, and deltas. Their lithology and structure are described on pages 232-236.

The lignite beds are of unknown extent, but they undoubtedly underlie several square kilometers and probably lie beneath all the dissected lowland near Camp Perrin except a small part near the northern border. They are concealed by alluvium except along some of the streams and ravines.

In the section exposed on La Ravine du Sud (see p. 234) there are at least three or four beds of lignite that are fairly free from partings of impure lignite and clay, ranging from 50 centimeters to 1 meter in thickness. The other beds contain so much incombustible material that they are worthless. Other beds higher in the section might be found by exploring the gravel-covered region to the south. The thickest well-exposed bed is 90 centimeters in thickness. Another poorly exposed bed seems to be nearly a meter thick. On La Rivière there are at least three

[1] Tippenhauer, L. G., op. cit., p. 195, 1901.

[2] Nau, Eugène, one of several articles on the mineral deposits of the Republic in Le Moniteur, 1859-1860. Published also in La République, 1859-1860. These reports were not examined.

[3] Thomasset, Henri, Rapport sur les gisements de charbon de l'Asile et du Camp-Perrin (addressé à Monsieur le Secrétaire d'État des Travaux Publics) : Le Moniteur, 53e Année, No. 46, pp. 358-359, Port-au-Prince, 8 juin, 1898.

beds, and possibly more. The thickest is 2 meters thick but contains many partings of clay. In one bed 40 centimeters of pure lignite was found. The beds appear to change abruptly in thickness and grade along the strike.

The lignite is black and has a bright luster. It contains many joints, and the joint faces are smooth and shining. Samples taken from outcropping ledges, unlike samples of lignite taken from the Central Plain, contain few cracks, and the material breaks up along joint planes. It has the appearance of a coal of subbituminous rank. The analyses given below show that this appearance is deceptive. The apparent high rank is due primarily to the folding of the beds, as the jointing is the result of crumpling.

The following table gives the results of analysis of two samples. Sample 1 was collected from bed 33 of the section measured on La Ravine du Sud (p. 234); sample 2 was collected from the best bed, about 40 centimeters in thickness, exposed on La Rivière. The samples were collected as described on page 482, except that two channels were cut for sample 1, and three channels for sample 2. The channels were spaced at intervals approximately equal to the thickness of the beds. No effort was made to exclude partings of impure lignite or carbonaceous clay, such as would have to be taken in mining.

Analyses of lignite from Camp Perrin.

[Made at the Pittsburgh laboratory of the United States Bureau of Mines; H. M. Cooper, chemist.]

Form of material analyzed.	Proximate analysis.				Ultimate analysis—sulphur.	Heating value (calories).
	Moisture.	Volatile matter.	Fixed carbon.	Ash.		
Sample 1:						
As received	23.51	22.90	16.53	37.06	0.73	2,270
Air dried	15.95	25.17	18.15	40.73	.80	2,494
Moisture free	....	29.94	21.61	48.45	.95	2,968
Moisture and ash free	....	58.08	41.92	....	1.84	5,758
Sample 2:						
As received	22.08	21.87	12.98	43.07	1.42	1,905
Air dried	14.80	23.92	14.18	47.10	1.55	2,083
Moisture free	....	28.07	16.66	55.27	1.82	2,445
Moisture and ash free	....	62.75	37.25	....	4.07	5,466

The analyses show a lower percentage of moisture than that in the Maïssade lignite. If the lignite in both regions were mined samples from underground workings would contain a higher percentage of moisture, although the amounts of moisture in weathered samples are probably comparable. The lignite from Camp Perrin has a much lower ratio of fixed carbon to volatile matter than the Maïssade lignite, indicating that

it probably is an undeveloped cannel coal. It contains a high percentage of ash and has low heating value, which is due principally to the large amount of incombustible material in the partings.

Thomasset[1] recorded the following two analyses, which were made in Paris:

Analyses of Camp Perrin lignite.

	1	2
Moisture	27.74	24.10
Volatile matter	27.06	31.90
Fixed carbon	27.98	31.83
Ash	17.22	12.17
Heating value in calories (not dried)	3,466	4,200
Heating value in calories (dried)	5,050	5,660

In the ratio of fixed carbon to volatile matter these analyses are different from those given on page 484. The samples may have come from other beds of different composition. Their high heating value indicates that they were picked samples, free from impurities. Thomasset states that about 2 tons of this lignite was shipped to Port-au-Prince and burned in the workshop of the street railway company, where it readily produced steam.

Relative Heating Value.

The relative value of fuels is shown by their heating value. The only industrial establishments in the Republic that use large quantities of fuel are the electric light plants, ice factories, sugar mills, and railroads. Wood is the only fuel now used except the small amounts of coal used in the railroad shops. Most of the wood used in Port-au-Prince is that of the leguminous tree called bayahonde, which grows in the Cul-de-Sac Plain. So far as known no tests have been made to determine the heating value of bayahonde wood. The heating value of the lignite of Maïssade and Camp Perrin as compared to wood is graphically shown in Figure 31.

In this graph the wood burned as fuel in the Republic is given an arbitrary heating value of 3,000 calories for dry wood and 2,250 calories for green wood.[2] The heating value of some coals from the United States is given in the same graph.

At the present time wood for fuel in Port-au-Prince costs 95 cents per cubic meter delivered, weighing about 385 kilograms, or $2.47 per metric ton.[3] If it is assumed that this wood is green and has a heating value of 2,250 calories the heating value of the wood as compared to the heating value of the better grade of lignite of Maïssade (sample No. 1 of

[1] Thomasset, Henri, op. cit., p. 359, 1898.

[2] These figures are based on conversions of the heating value of several woods from the United States given in The use of wood for fuel: U. S. Dept. Agr. Bull. 753, pp. 28-30, 1919.

[3] Based on the cost of wood purchased by the electric company of Port-au-Prince. Information supplied by the Engineer-in-Chief.

analysis on p. 482) is as 2,250 is to 3,737; or, if wood costs $2.47 per metric ton, consumers in Port-au-Prince could afford to pay $4.14 per metric ton for this lignite.

The present price of semibituminous coal from the United States, such as the coal from the New River field of West Virginia (*m*, in Fig. 31), delivered in Port-au-Prince is not known. During the two months preceding the strike of April, 1922, the average price of such coal delivered at Hampton Roads, Va., was $4.62 per ton (2,000 pounds avoirdupois weight), or $5.09 per metric ton. Freight, dockage charges, and insurance probably would bring the price delivered at Port-au-Prince to about $18 per metric ton.

FIGURE 31.—Diagram showing the heating value of Maïssade and Camp Perrin lignite as compared with other coals and wood.

If green wood is worth $2.47 per metric ton and American semibituminous coal $18 per metric ton the lignite from Camp Perrin and Maïssade has the following value:

Comparative value of wood, lignite, and coal.

	Green wood at $2.47 per metric ton.	West Virginia semibituminous coal at $18 per metric ton.
Camp Perrin lignite (No. 2)	$2.09	$4.20
Green wood	2.47	4.97
Camp Perrin lignite (No. 1)	2.49	5.01
Maïssade lignite (No. 2)	2.85	5.72
Dry wood	3.29	6.62
Maïssade lignite (No. 1)	4.10	8.24
West Virginia semibituminous coal	8.96	18.00

Although this table is based on some unknown factors it gives an idea of the relative value of the lignite. Coal at $18 per metric ton is too expensive for ordinary industrial uses, as with coal at that price wood is worth twice its present cost.

The Camp Perrin lignite therefore can not compete with wood at the present time. In composition this lignite resembles undeveloped cannel coals of Tertiary age in Texas, but its heating value is lower. Picked samples would show much higher heating values than those given on page 484, but picked samples could not be mined. The beds are steeply inclined and would have to be worked from steeply inclined or vertical shafts. The abrupt change in dip and the faulting would increase the difficulties. The rocks that overlie the lignite beds are soft and could not be supported without extensive timbering. These conditions and the distance to industrial centers prohibit the exploitation of these beds.

Under present conditions of transportation the lignite at Maïssade can hardly be utilized. In composition and heating value the grade of lignite represented by sample 1 in the table on page 482 closely resembles the lignite of Eocene age in Montana and North Dakota. If a railroad could be extended into the Central plain this lignite could compete with wood under favorable conditions of production, even at the present time. There are beds containing enough lignite of this grade to be mined. Near the trough of the Central Plain syncline, where the beds dip gently, the lignite could be mined in open cuts by stripping the overburden. If the demand for fuel increases as the available supply of wood becomes exhausted, these beds should be examined to determine the available tonnage, methods of production, and methods of treatment.

Lignite as mined contains a high percentage of water, which lowers its heating value. When exposed to the air it rapidly loses some of its moisture and "slacks," and is then an unsatisfactory fuel. If the lignite is to be used at a distance from the deposits it would require some treatment in order to obtain from it the maximum amount of heat. In Germany "brown coal" of lower rank than the lignite of Maïssade is successfully briquetted without the use of a binder after being dried. The lignite of North Dakota has not yet been treated on a commercial scale, but the results of tests indicate that the most successful treatment is to carbonize the lignite and briquet the carbonized residue with the aid of a binder.[1] An elaborate series of tests probably would be required to determine the best method of treating the lignite of Maïssade. It is possible that it would not "slack" too rapidly to be used in near-by industrial centers. When brought from the mine small pieces "slack" less rapidly than large pieces. Samples taken from the weathered outcrop on Rivière Frio in February, 1921, were cracked but had not crumbled by September, 1922. Samples from underground workings would, however, contain more moisture and would "slack" more rapidly.

[1] See Babcock, E. J., Economic methods of utilizing western lignites: U. S. Bur. Mines Bull. 89, 1915.

OIL.

Possible Oil Resources of the Central Plain.

No wells have been drilled in the Republic of Haiti to ascertain the possibility of obtaining oil in commercial quantities. The detrital Miocene rocks are the most favorable beds, both as mother rocks and as reservoirs. These rocks attain their maximum thickness in the Central Plain. An account of the possible oil resources of the Miocene rocks of the Central Plain has already been published,[1] and the following paragraphs are taken from this account.

STRATIGRAPHY OF THE MIOCENE ROCKS.

The Miocene rocks of the Central Plain, or Artibonite group, consisting in ascending order of the Madame Joie formation, Thomonde formation and Maïssade tongue, and Las Cahobas formation, have an estimated thickness of 1,400 meters. Their stratigraphy is fully discussed on pages 161-206, and their distribution is shown on Plate XXXVI.

STRUCTURE OF THE CENTRAL PLAIN.

Structurally the Central Plain is a large southeastward-plunging syncline, modified by secondary anticlinal and synclinal folds, between the Massif du Nord and the Montagnes Noires. The axis of the syncline trends northwestward, parallel to the structural trend of the mountains.

Northwestern Part.

Southwest limb of syncline.

The northwestern part of the plain is an asymmetrical syncline that has steeper dips on the southwest limb than on the northeast limb. (See Pl. XXXVI, section *A*-*A*′.) The structure of the southwest limb is modified by secondary anticlinal and synclinal folds and by thrust faults.

FOND BLEU DOME.

The anticlinal fold on the southwest limb of the syncline, which apparently plunges both northwestward and southeastward, is called the Fond Bleu dome, from the name of the stream flowing across its northwest end. The crest of the dome is about 3.5 kilometers in an air line southwest of the town of Maïssade, or about 4.8 kilometers west-southwest of Maïssade by the trail to Madame Joie. The dome is asymmetrical and has steep dips to the northeast, toward the main synclinal trough, except for a distance of 0.5 kilometer from the crest, where the dips are relatively gentle. (See Pl. XXXVI, section *C*-*C*′.) Farther northeast for 0.6 kilometer the dip is as high as 65°. Northeast of this narrow belt of high dips the beds

[1] Woodring, W. P., Stratigraphy, structure, and possible oil resources of the Miocene rocks of the Central Plain, 19 pp., map, Rep. Haiti Geol. Survey, 1922.

flatten in a short distance and dip at the rate of about 6° to the trough of the main syncline, which lies about 3.7 kilometers northeast of the crest of the dome. In the trough of the syncline the beds are probably 400 meters lower structurally than on the crest of the dome. On the southwest limb the beds dip from 5° to 30° for 1.5 kilometers from the crest and flatten in the trough of a narrow, sharply folded syncline that separates the dome from the mountain front. The southeastern part of the dome was not examined, but apparently the area of closure is about 5 kilometers long and has a maximum width of 1.5 kilometers.

The lowest rocks exposed on the crest of the dome are sandstones and siltstones in the lower part of the Thomonde formation. The conglomerates and coarse sandstones in the middle part of the Thomonde formation form a "rim rock" around the dome.

Between the syncline southwest of the dome and the mountain front the lowest beds in the Thomonde formation are probably thrust northeastward over higher beds in the Thomonde formation. Farther northwest the lower part of the Thomonde formation is thrust northeastward over the Maïssade tongue. (See Pl. XXXVI, section *B-B'*.) More extensive thrust faults may separate the older limestones from the detrital Miocene rocks along the mountain front, but the mountain front was not examined.

Northeast limb of syncline.

PLUNGING ANTICLINE BETWEEN MAÏSSADE AND PIGNON.

The southeastward extension of the Oligocene rocks along Rivière Bouyaha and the strikes and dips recorded in the Miocene beds along the trail between Maïssade and Pignon indicate that a southeastward-plunging anticline extends into the plain on the northeast limb of the syncline. This anticline parallels a southeastward-plunging secondary syncline to the east, which accounts for the northwestward extension of Oligocene beds beyond St.-Raphaël.

Southeastern Part.

Southwest limb of syncline.

In the enlarged southeastern part of the plain the southwest limb of the main syncline is much wider than the northeast limb and is characterized by asymmetrical anticlines that emerge from the mountains and plunge into the plain.

WEST SIDE.

On the west side of the plain a bulging compound anticline strikes off from the mountains. Three asymmetrical anticlines are superimposed on this compound anticline and plunge southeastward into the plain. All the anticlines have steep northeastward dips and more gentle south-

westward dips. The crests of the anticlines are approximately parallel to one another and to the trough of the main syncline.

Thomonde anticline.—The northern anticline is the largest of the three folds. It was called the Thomonde anticline by Jones,[1] as the town of Thomonde stands near its crest. The crest of the anticline extends for an unknown distance southeastward into the plain. The rate of plunge of the crest is about 8° near the mountains, but it decreases southeast of Thomonde. The fold is sharply asymmetrical near the mountains (see Pl. XXXVI, section *D-D'*), but the northeastward dip decreases markedly in a short distance out toward the plain, and the fold becomes virtually symmetrical southeast of Thomonde (see Pl. XXXVI, sections *E-E'* and *F-F'*). The beds on the northeast limb dip from 5° to 20° for a distance of 1.8 kilometers from the crest. Near the mountains the northeast limb steepens abruptly farther from the crest—for example, on the trail from Thomonde to Hinche there is a belt about 0.5 kilometer wide where the dip is from 70° to 80° or even 90°. Northeast of this belt of steep dips the beds flatten rapidly toward the trough of the main syncline. Southeast of the trail from Thomonde to Hinche the northeast limb is not so steeply tilted. North of Thomonde the steepest dips are from 40° to 60°, and northeast of Thomonde, on the trail to Thomassique, the maximum dips are 30° to 40°. (See Pl. XXXVI, section *E-E'*.) Still farther to the southeast the dip of the beds on the northeast limb is more gentle as the fold plunges into the plain. (See Pl. XXXVI, section *F-F'*.) The trough of the main syncline lies about 4.5 kilometers northeast of the crest of the anticline. In the trough of the syncline the beds are about 800 meters lower structurally than on the crest of the anticline at Thomonde. The beds on the southwest limb dip southwestward at a rate of 5° to 12° to the trough of a shallow plunging syncline.

Successively older rocks arch over the crest of the anticline northwestward toward the mountains. The conglomerates at the base of the Las Cahobas formation form a conspicuous pine-covered "rim rock" around the southeastern part of the anticline.

Chamouscadille anticline.—The middle one of the three plunging anticlines on the west side of the plain is called the Chamouscadille anticline, from the name of the rural section in which it is situated. The Chamouscadille anticline resembles the Thomonde anticline in many features, but it plunges more steeply into the plain. The crest of this anticline is about 7 kilometers southwest of the crest of the Thomonde anticline and about 3 kilometers southwest of the trough of the shallow syncline between the two anticlines. (See Pl. XXXVI, section *E-E'*.) Along the trail from Las Cahobas to Thomonde the crest plunges southeastward at the rate of about 6°. Near this trail the dip of the beds on the northeast limb is 10°.

[1] Jones, W. F., A geological reconnaissance in Haiti; a contribution to Antillean geology: Jour. Geology, vol. 26, p. 736, 1918.

Toward the mountains the dip of the beds on the northeast limb increases markedly; along the trail from Thomonde southwestward across the mountains to Mirebalais it is 55°. On the southwest limb the beds dip from 5° to 10° for a distance of about 2 kilometers to the trough of a shallow plunging syncline similar to the syncline on the northeast side of the anticline.

Conglomerates at the base of the Las Cahobas formation form a "rim rock" around the southeastern part of the anticline, as on the Thomonde anticline.

Ayaye anticline.—The southernmost of the three anticlinal folds is called the Ayaye anticline, from Rivière l'Ayaye, which flows across its crest. This anticline is the shortest and least conspicuous of the three plunging anticlines on the west side of the plain. Its crest is about 3.8 kilometers southwest of the crest of the Chamouscadille anticline and about 1.8 kilometers southwest of the intervening shallow syncline. The trough of the syncline betwen the Ayaye anticline and the mountains on the south side of the plain is about 3.5 kilometers southwest of the crest of the anticline. The crest plunges southeastward at the rate of 8° where Rivière l'Ayaye crosses it. This anticline is apparently not so asymmetrical as the other two, but the dips on the limbs were not measured.

SOUTH SIDE.

Belladère anticline.—On the south side of the plain near the Dominican border an asymmetrical anticline emerges from the mountains and plunges northwestward into the plain. This fold is called the Belladère anticline, as the town of Belladère is on its north limb. The Belladère anticline may be the prolongation of the Chamouscadille anticline, but it is not known whether the fold extends across the interior of the plain, and the topographic base map is not so accurate for this part of the plain as for the area farther west. The Belladère anticline resembles the plunging anticlines on the west side of the plain in many features, but it differs from them in having steep dips on the southwest limb and more gentle dips on the northeast limb. (See Pl. XXXVI, section *G-G'*.) The crest of the fold is about 2.5 kilometers northeast of the trough of a narrow, sharply folded syncline that widens as it plunges into the plain. On the crest of the anticline the beds are not well exposed, but southwestward from the crest the dip of the beds on the southwest limb increases to 55° in a distance of about 1 kilometer. The dip on the northeast limb was measured only near Belladère, where the beds dip from 10° to 20° almost due north.

A high "rim rock," formed by the basal beds of the Las Cahobas formation, incloses the northwestern part of the anticline, as on the plunging anticlines on the west side of the plain.

Northeast limb of syncline.

STRUCTURAL TERRACE NEAR THOMASSIQUE.

On the northeast limb of the syncline the beds dip southwestward toward the trough. Along the trail from Thomonde to Thomassique they rise from the trough of the syncline at a rate of dip that increases rather uniformly to 15° or 20° near Thomassique. (See Pl. XXXVII, *A*.) Northeast of Thomassique there is a belt about 4.5 kilometers wide where the dip flattens to 7°. Farther northeast the beds are upturned against the mountains in a belt about 3 kilometers wide, where the dip is as high as 20°. This structural terrace coincides with the wider part of the plain.

POSSIBLE SOURCE OF OIL.

The Thomonde formation is the most promising possible source of oil in the Central Plain. Beds in this formation, especially in its middle and upper parts, contain the remains of a great variety of marine organisms. The Maïssade tongue, which is a coastal-swamp facies of the middle and upper parts of the Thomonde formation, contains an abundance of coastal-swamp vegetable débris. Seeps of oil at localities indicating that the oil is contained in the Thomonde formation have been reported by several people but were not seen during the reconnaissance. There are no large seeps, residues, or mud volcanoes like those found in Trinidad, Venezuela, and Columbia, where rocks of the same age contain oil.

RESERVOIRS.

The Thomonde formation also contains rocks suitable to form reservoirs of oil. All parts of the formation include beds of sandstone and sandy siltstone that are more porous than the interbedded compact clayey siltstone. The conglomerates and coarse sandstones in the lower part of the Las Cahobas formation, however, are perhaps more suitable for reservoirs and they overlie the possible source of oil.

STRUCTURE AS AFFECTING ACCUMULATION OF OIL.

If oil were present in any of the beds underlying the plain it would collect in structural traps. The Thomonde, Chamouscadille, and Belladère anticlines are the most favorable structural features. If the crests of these folds extend across the plain they are probably arched into domes in the interior of the plain. Such domes would be the most favorable localities to test the possibility of obtaining oil in commercial quantities. In the interior of the southeastern part of the plain the beds that are possibly petroliferous are covered by the Las Cahobas formation and the base of the Thomonde formation is from 300 to 500 meters below the surface, the depth depending principally on the structure. Pools will hardly be found on any of the plunging anticlines inside the rim formed by the base

A. SOUTHWARD-DIPPING BEDS ON THE NORTHEAST SIDE OF THE CENTRAL PLAIN NEAR THOMASSIQUE.

B. MAIN ENTRANCE TO THE CITADELLE OF CHRISTOPHE.

The citadelle is constructed of roughly shaped blocks of limestone and of bricks.

of the Las Cahobas formation, for the possibly petroliferous beds near their outcrop would lose the oil through flushing by artesian circulation. Although the entire Central Plain syncline plunges southeastward, it is not likely that the deeper beds in the interior of the plain have been flushed by ground water, because impervious beds crop out around the edge of the plain and its southeastward prolongation, the San Juan Valley, and because the floor of the syncline is far below sea level and apparently has never been above sea level since the beds were laid down.

RELATIONS TO FIELDS NEAR BY.

The only oil wells on the island of Haiti are those near Azua, in the Dominican Republic, where seeps have been known for a long time. The so-called Azua field has been described by Condit and Ross,[1] and the following summary is drawn from their account. Six wells have been drilled, and all except one are within a few hundred meters of the principal seep. According to reports, oil was found in all the wells at a depth of less than 290 meters. The production of the wells is not definitely known. All the wells were destroyed by salt water, which entered at a greater depth and was not controlled. The oil, a heavy, viscous oil of 19° to 21° Baumé, apparently contained no gasoline.

The possibilities of the Azua field have not been adequately tested. The rocks near the seeps are crumpled and faulted, and no attempt has been made to reach the petroliferous beds at a favorable locality farther from the outcrop. The oil obtained is probably not typical, as near the outcrop it may be modified by fractionation or by chemical reactions with downward-circulating ground water.

The rocks that crop out at the seeps in the Azua field are apparently equivalent to the lower part of the Artibonite group of the Central Plain, but the two areas of Miocene rocks are separated by a northeastward extension of the Sierra de Neiba.

CONCLUSIONS AS TO POSSIBILITY OF FINDING OIL.

The lithology and structure of the Miocene rocks of the Central Plain warrant a thorough search for oil. The interior of the southeastern part of the plain should be examined for domes along the crests of the Thomonde, Chamouscadille, and Belladère anticlines. The base of the Las Cahobas formation and the upper and middle parts of the Thomonde formation, which contain the most promising reservoirs for oil, would be within reach of the drill on such domes. Test wells should reach the upper Oligocene limestone, if oil is not found in higher beds, in order to test all the Miocene rocks. The region near Thomassique, where there is

[1] In Vaughan, T. W., Cooke, C. W., Condit, D. D., Ross, C. P., Woodring, W. P., and Calkins, F. C., A geological reconnaissance of the Dominican Republic: Dominican Rep. Geol. Survey Mem., vol. 1, pp. 223-225, 1921.

a structural terrace, should be tested if it is proved that the underlying rocks are petroliferous elsewhere.

The northwestern part of the plain is not so promising as the southeastern part. The lower part of the Thomonde formation is exposed on the Fond Bleu dome, and the thicker coarse detrital rocks of the same age on the plunging anticline between Maïssade and Pignon are probably entirely delta and flood-plain deposits.

Possible Oil in Other Regions.

The Artibonite Valley resembles the Central Plain in many features, as structurally it is a northwestward-plunging syncline, modified by secondary anticlinal and synclinal folds. It also is floored with the Miocene rocks of the Artibonite group. Figures 12 (p. 207) and 13 (p. 208) show that a secondary anticline flanks the major synclinal trough on both sides of the valley. Except in the upper part of the valley the Miocene rocks consist principally of marl and limestone, which do not contain the rich fauna of deposits of the same age in the Central Plain. The Miocene rocks of the Artibonite Valley are therefore not so promising, either as a possible source of oil or as reservoirs.

Miocene rocks probably floor the Cul-de-Sac Plain under the cover of alluvium, but they are so completely concealed that their structure is indeterminable from surface observations. Their lithology, as observed at their outcrop along the borders of the plain, does not warrant any exploration with the drill.

Reports of asphalt near Étang de Miragoâne have been repeated in several accounts of the mineral resources of the Republic. Although no attempt was made during this reconnaissance to find the deposits, the geology of the region indicates that the reports are not authentic.

ROAD MATERIAL.

Present State of Road Building.

As compared with the area of the Republic, the length of improved roads already built is very small, and most of them are not suited for heavy traffic. Roads that will bear heavy traffic are needed in the plains to facilitate agricultural development, and trunk lines connecting the larger cities and towns are desirable.

Although an unlimited amount of good material for road making is available, much of it is inconveniently situated, and a great deal of easily accessible but inferior material is therefore used.

Along the coast much of the soft coralliferous limestone of Quaternary age is used. It binds well but is too soft except for light traffic. Much gravel from stream beds and older gravel beds is used, especially in the Cul-de-Sac Plain. If properly graded and carefully laid it is reasonably satisfactory, although it also is rather soft. The impure

cherty limestone at Cap-Haïtien is used extensively on the streets of that city with good results. In the mountainous regions hard rock is generally available, but it is not much used because of the lack of machinery for crushing it and preparing the roadbed. Some of the stony residual soils of the mountain areas, when properly graded and dressed with a little gravel, make good roads for light traffic.

Tests of Samples of Road Material.

The Bureau of Public Roads of the United States Department of Agriculture tested six samples of material either used or available for use in road making in the Republic. Four of these samples were rock and were tested for use as courses in water-bound macadam. Two samples of residual chert and gravel were tested for use in surfacing roads. The cementing value of the rocks was not tested. The results of tests of the four samples of rock are given in the following table:[1]

Results of physical tests of some rocks available for road building.

Sample No.	Locality.	Kind of rock.	Specific gravity.	Percentage of water absorbed.	Per cent of wear.	French coefficient of wear.	Hardness.	Toughness.
1	Near Limbé	Amphibolite	3.01	0.60	5.8	6.9	18.7	22
2	Near Acul Samedi..	Quartz diorite	2.74	0.34	2.8	14.3	18.0	15
3	Cap-Haïtien	Chert (weathered).....	2.35	2.77	9.1	4.4	17.7	[a]
4	Cul-de-Sac Plain ...	Limestone (boulders)...	2.64	0.67	4.4	9.1	14.7	7

[a] Variable.

The amphibolite (sample 1) consists mainly of hornblende and magnetite. It is a dense dark-gray rock of unusually high specific gravity. It belongs to the early Mesozoic volcanic series but has been metamorphosed by a near-by intrusion of quartz diorite. The sample was collected in a road cut on the north slope of Plaisance Mountain, about 4 kilometers south of Limbé. The hardness and toughness are high, and probably the rock would bind fairly well. The percentage of wear is rather high; nevertheless, this rock is considered the best road-building rock tested.

The quartz diorite (sample 2) contains about 88 per cent of the essential minerals, plagioclase, quartz, and hornblende. The accessory minerals magnetite and biotite constitute about 3 per cent and the secondary minerals kaolin, chlorite, and limonite about 9 per cent of the rock. This rock is typical of the quartz diorite that covers large areas in the Massif du Nord, from Grande Rivière du Nord eastward

[1] For description of the methods of testing, see Jackson, F. H., jr., Methods for the determination of the physical properties of road-building material: U. S. Dept. Agr. Bull. 347, 1916.

to the Dominican border. The sample was collected from boulders in the bed of Rivière Marion near Acul Samedi. The hardness and toughness are high and the percentage of wear low, but rocks of this type do not bind well. The rock might be satisfactory in lower courses if used with a good binding material.

Sample 3 comes from the impure cherty limestone, probably of Cretaceous age, that crops out in small areas in the Morne du Cap. The sample was collected in a quarry near the Civil Prison at Cap-Haïtien. It is composed mainly of very fine angular fragments of quartz embedded in a cryptocrystalline siliceous matrix. A little secondary limonite and sericite are present. Near the surface the rock is much shattered and badly weathered. The percentage of wear is high, but the hardness is also high and the binding power is probably good. Material that is not too badly weathered should do fairly well for courses in macadam roads.

Sample 4 represents the harder Eocene and Oligocene limestone of the Republic. It was obtained from large boulders in a gravel pit about 3 kilometers west of Pont Beudet, on the Cul-du-Sac Plain. In hardness and toughness the limestone is inferior to the other rocks tested, but in its percentage of wear it compares favorably with them. Moreover, the binding power of limestones generally is excellent, and the binding power of this sample may be judged from that of sample B of the gravel, which was taken from the same pit. (See below.) The Bureau of Public Roads states that this rock "is not sufficiently durable to be used in water-bound macadam surface except where traffic will be light." However, the results of the physical test compare favorably with those of many limestones that are successfully used in the United States.

Two samples of material were tested for use as surfacing material. One is a finely divided and much-weathered residual chert from the same quarry from which rock sample No. 3 was obtained. The other is a gravel from the gravel pit at which rock sample No. 4 was collected. The results of the tests are as follows:

Results of tests of samples of residual chert and gravel.

Sample.	Locality.	Kind of material.	Principal constituents.	Loss by washing (silt and clay) (per cent).	Cementing value.
A	Cap-Haïtien	Crushed rock.	Angular fragments of weathered chert with considerable fine chert.	26.0	[a]
B	Cul-de-Sac Plain ..	Sand, clay, gravel.	Rounded fragments of limestone, quartz, basalt, and chert. Quartz sand and calcareous clay.	2.9	88

[a] Impossible to test.

Mechanical analyses of two samples of residual material.

			A	B
			Per cent.	*Per cent.*
Gravel (material retained on ¼-inch screen)			34	72
Sand (material passing ¼-inch screen)			66	28
Gravel (material retained on 1½-inch screen)			0	16
passing 1½-inch screen but retained on 1-inch screen)			11	29
1	¾	....	10	14
¾	½	....	27	21
½	¼	....	52	20
Sand (material retained on 10-mesh screen)			23	28
passing 10-mesh screen but retained on 20-mesh screen)		....	15	12
20	30	....	7	10
30	50	....	5	14
50	100	....	4	13
100	200	....	5	8
200		....	41	15

Sample A represents the finer material that is abundant at the surface of weathered exposures of the impure cherty limestone. The Bureau of Public roads says that this material "should prove satisfactory as binder for broken rock in waterbound macadam road construction. Although the cementing value test could not be made, experience has shown that this type of material has good binding properties." As a matter of fact, it is used with good results as a top dressing on the streets of Cap-Haïtien.

Sample B is typical of the finer material obtained at several gravel pits in the Cul-de-Sac Plain and resembles many other gravel deposits in the Republic that are composed predominantly of limestone pebbles. The cementing value of this gravel is very good, and although rather soft it gives good results under light traffic. Fairly good roads can be constructed entirely of this gravel by using the coarser material for the lower layers or by crushing the large boulders and carefully grading the gravel. The highway from Croix-des-Missions to Pont Beudet was constructed entirely of this gravel, and although the traffic is rather heavy the road bed has not deteriorated rapidly. The highway from Port-au-Prince to Croix-des-Missions shows the results of using ungraded gravel, as the roadbed deteriorated rapidly when large cobbles near the surface became loose.

Summary of Available Material.

The value of road material depends not only on its physical properties but also on its accessibility and cost. The best rock in the Republic for use in courses in water-bound macadam roads are the extrusive igneous rocks, such as basalt, andesite, and dacite. The amphibolite tested (sample 1) is a somewhat metamorphosed rock of this type. Probably all the basalts, which comprise nearly all the igneous rocks of the Southern

Peninsula, would make good roads. Large areas of basaltic and andesitic rocks crop out in the Massif du Nord from Grande-Rivière westward to Port-de-Paix and in the Terre-Neuve region. Small exposures of basaltic and andesitic rocks also occur near the road between Dessalines and Gonaïves. Metamorphosed basaltic rocks also are known at accessible locations on the North Plain near the head of Acul Bay and at the southern border of the plain east of Le Trou. Other basaltic rocks crop out at the foot of the mountains near Thomazeau and Maneville.

The coarsely crystalline intrusive igneous rocks, such as quartz diorite and granodiorite, occur mainly in the Massif du Nord, from Grande-Rivière eastward to the Dominican border. These rocks are less desirable as road material and probably need not be used to any great extent.

The hard Eocene and Oligocene limestones will make good roads where traffic is not too heavy, and because of their very wide distribution they probably will be used extensively. They occur in practically every mountain range in the Republic.

Gravel is found in the plains and valleys where roads are especially needed. It is the cheapest and most accessible road material available, for machinery would be required to quarry and crush the igneous rocks and limestone. An extensive program of highway construction is entirely unwarranted at present, and highways constructed of gravel would be satisfactory in the more thickly populated plains. The gravels are very irregular in texture and composition, and careful grading is necessary to assure good results. The best gravel, composed mainly of fragments of igneous rocks, is found in extensive areas only on the North Plain.

The soft coralliferous limestones of the coast and of the Miocene formations are better than dirt but are inferior to any of the other rocks for road material.

BUILDING STONE.

Many of the walls, aqueducts, and other structures built during and since the colonial period consist of rubble masonry, made of rough field stones laid in thick mortar. Bricks were used liberally wherever the stones did not fit well, as in arches and at corners. Limestone boulders generally were used because they were most common. Occasionally, especially at Port-au-Prince and Cap-Haïtien, large coral heads from the living reefs take the place of boulders. Many of the colonial structures of this type were well built, and parts of them are still intact.

At Port-au-Prince considerable chalk from the hardened upper crust of the Quaternary conglomerate is used in buildings and for foundations. It is very easily quarried but too soft to shape well. The rough, irregular lumps are laid in thick lime mortar. The life of this material appears to be short, and failures of structures in which it has been used are rather common.

Near the coast soft coralliferous limestones of Quaternary age have been quarried at a few places. The best quarry seen was about a kilometer north of Môle St.-Nicolas, near the road to Jean Rabel. The limestone is fairly hard, and the thickness of the beds is from 20 to 50 centimeters. Good dimension stone was obtained and used in the extensive fortifications around the harbor. The stone has lasted well, for the forts have not been repaired for more than a hundred years.

The only place observed where the older hard limestones have been used to any great extent is in the citadel at La Ferrière, which was constructed largely of Eocene limestone from the mountain on which it stands. The stone is roughly shaped and is laid as coursed rubble. Bricks were used freely, however, particularly in facing the openings (Pl. XXXVII, *B*). This structure has stood more than a century, and the main walls are in reasonably good condition, indicating that the stone is durable.

Some of the dense, uniformly colored Tertiary limestones take a high polish and would be suitable for use in interior decoration.

A good building stone must fill several requirements. In the first place it must be strong enough to resist crushing. With the possible exception of the chalk at Port-au-Prince, all the rocks of the Republic have a crushing strength much greater than is needed in ordinary structures.

The next desirable property is durability. The chalk mentioned above and the very soft, poorly consolidated beds in the coralliferous limestones are not very durable, but all the harder limestones of Eocene or Oligocene age and most of the igneous rocks would last well. Climatic conditions are favorable, as there is no frost. Moreover, there is little of the smoke and injurious gases, such as cause deterioration of building stones in manufacturing districts.

Color is important. The color of the stone in any building should be fairly uniform, but the shade is largely a matter of taste and of prevailing opinion. The coralliferous limestones weather to a monotonous drab or gray. The Eocene and Oligocene limestones would be whiter and probably more attractive. Some of the igneous rocks, particularly the quartz diorites, would be pleasing in appearance, although they are not highly colored. Care must be taken in selecting them to get material free from pyrite, which weathers and produces unsightly brown stains. The pink quartz diorite in the mountains south of Jean Rabel, which is probably the most attractively colored stone observed, unfortunately contains much pyrite. Some of the gray quartz diorites near Grande-Rivière du Nord also contain pyrite.

The cost of building stone depends principally on the difficulty of quarrying. The limestones are fairly soft, and their bedding facilitates quarrying. Most of the Eocene and Oligocene limestone is too thin-bedded to furnish good dimension stone, but thicker beds can be found by careful search. Igneous rocks generally can be worked easily only where joints

occur at convenient intervals to assist in breaking out the stone. The quartz diorites have such jointing at many places. The basalts, however, are at many places too minutely jointed to yield large blocks. Moreover, basalt is generally very tough and difficult to work.

Last of all, the location of quarries is determined largely by accessibility either to the locality where the stone is to be used or to transportation facilities. The Quaternary limestone of Môle St.-Nicolas is well located for transportation by water. Similar stone probably could be obtained near the railway on the terraces of coralliferous limestone on Cap-St.-Marc. The quartz diorites of the north could be obtained near the railway between Grande-Rivière du Nord and Bahon, although they are not so handsome there as farther east. At present there is little demand for stone of this kind.

ROCK FOR CONCRETE.

Rock for concrete should be reasonably hard and should consist of material so graded in size that the smaller pieces will fill the open spaces between the larger ones. A rough surface probably increases the binding power, and for this reason crushed stone has been preferred by many engineers to rounded gravel, some even prescribing that gravel, if used at all, should be crushed. Experience in the Republic of Haiti has shown that this is generally unnecessary and that the natural gravel makes excellent concrete. The gravel is composed mainly of pebbles of hard limestone or of igneous rock, either of which are satisfactory. Crushed stone from these same rocks would of course be equally satisfactory. However, machinery for crushing has not been available up to this time, and breaking by hand is so expensive that gravel has been used almost entirely.

LIME.

A great deal of lime is made in the Republic for domestic use. Most of it is used for mortar or for whitewash. All the pure limestones are burned to make lime, and occasionally coral heads from the living reefs are used. Small quantities of lime are made by mixing wood and stone and burning in heaps in the open air. For larger quantities crude kilns are made, preferably on chalky hillsides. A pit is dug like a well, and an entrance is made at the base by a tunnel if necessary. The fuel is placed below and the rock above. By neither method can the rock be burned completely and evenly, and the product is inferior to that of carefully operated commercial plants.

Much of the limestone of the Republic is remarkably pure, as is shown by the two analyses in the following table. Rock of this kind makes a quick setting high-calcium lime.

Analyses of limestone.

Sample No.	Lime (CaO).	Magnesia (MgO).	Carbon dioxide (CO_2).	Silica (SiO_2).	Alumina (Al_2O_3) and ferric oxide (Fe_2O_3).	Total.
1	55.60	0.45	43.45	0.14	0.26	99.90
2	55.12	0.56	43.18	0.50	0.20	99.56

Sample 1 was obtained from the middle Eocene Plaisance limestone at the top of Mont Puilboreau between Ennery and Plaisance. Sample 2 was obtained from beach gravel about 3 kilometers southeast of Mont-Rouis, where the shore touches the base of the Chaîne des Mateux. It is composed of pebbles of hard Eocene limestone and possibly in part of Oligocene limestone. Of course not all the limestones of the country are so pure as these samples, but rock of equal purity is plentiful.

The amount of lime consumed in the Republic is probably equal to the output of a large modern factory. However, if such a plant were erected it could scarcely compete successfully with the inferior but cheap lime made by the present crude methods. If sugar refining, which requires lime of high purity and uniformity, should continue to increase a plant to supply this trade might possibly be successful. A factory located near Port-au-Prince doubtless could find satisfactory limestone on Morne Hôpital. Good limestone could also be obtained very near the railroad, about 3 kilometers southeast of Mont-Rouis, near the place where sample 2 was collected. Many other reasonably accessible localities could supply limestone of satisfactory quality.

MATERIAL FOR CEMENT.

The Republic of Haiti probably contains an abundance of raw materials suitable for the manufacture of Portland cement, although present economic conditions do not favor their utilization.

According to the United States Geological Survey,[1] "The ordinary Portland cement mixture, when made from normal and natural raw materials, contains about 75 per cent of lime carbonate ($CaCO_3$) and 20 per cent of silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3) together, the remaining 5 per cent including magnesium carbonate, alkalies, sulphur, and other unavoidable but unnecessary constituents." The United States Geological Survey states further[2] that the amount of silica present should be from two to three and one-half times the combined

[1] Eckel, E. C., Burchard, E. F., and others, Portland cement materials and industry in the United States: U. S. Geol. Survey Bull. 522, p. 41, 1913.

[2] Idem, p. 65.

amount of alumina and iron oxide. Magnesia should not exceed 3 or 4 per cent.

Occasionally a natural cement rock, an impure limestone of very nearly the right composition, is found, but generally it is necessary to mix different materials in proportions that will give a product of satisfactory chemical composition. As a rule, the calcium carbonate is supplied by limestone or marl, and the silica, alumina, and iron oxide by clay or shale. Free silica in the form of sand is highly undesirable, and chert greatly increases the difficulty of grinding. Grinding is much cheaper if all the ingredients are soft.

Pure limestone that would supply calcium carbonate is widely distributed in the Republic. Two typical analyses are given on page 501. Suitable clay or argillite is probably nearly as common. Analyses of two samples are given in the following table:

Analyses of materials that are possibly suitable for cement.

Sample No.	Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Carbon dioxide (CO_2).	Water (H_2O).	Total.
1	25.42	8.32	1.93	30.33	2.27	23.75	6.38	98.40
2	51.30	16.88	4.77	8.06	3.16	5.09	8.32	97.58

Sample 1 was obtained from a ravine near the bridge about 5 kilometers northeast of St.-Marc, on the road to Gonaïves. It represents the marl of Miocene age that underlies the surrounding valley and resembles other Miocene marls found at many places in the Republic. Sample 2 was obtained in a road cut about a kilometer south of the bridge over Les Trois Rivières near Plaisance, and represents beds of considerable thickness in the argillite, presumably of lower Cretaceous age, that underlies the Plaisance Valley and crops out elsewhere in the Massif du Nord.

Microscopic examination indicates that the samples contain little if any free silica (sand). The ratio of silica to alumina and iron in the two samples is very nearly the same, approximately 2.5 to 1, and is within the limits prescribed on page 501. However, the first sample contains a great deal of calcium carbonate and the second very little. In order to obtain a mixture of the composition specified on page 501, pure limestone, like that for which analyses are given on page 501, would have to be added to the marl (sample 1) in the proportion of about 80 parts by weight to 100 parts of marl. About 250 parts by weight of limestone would need to be added to the argillite (sample 2) to produce a similar mixture. However, materials that are chemically well proportioned do not always produce a good cement, and the results can be determined only by trial.

Possibly some of the brick clays, like those at l'Arcahaie, would be satisfactory for mixing with limestone to make cement.

In recent years the Republic of Haiti has imported about $100,000 worth of cement annually, and the importations are increasing, but a plant to furnish the domestic supply would not be warranted by such a volume of business. The location of cement plants is generally determined more by other factors, such as labor, transportation, nearness to markets, and fuel supply, than by the occurrence of suitable raw materials. There is now no suitable fuel supply for cement manufacture in the Republic, and unless oil should be found it probably will be impossible to establish a profitable cement industry.

CLAY FOR BRICKS.

The Republic produces nearly all the common building brick that it consumes. The largest brick factories are those near l'Arcahaie and near Cap-Haïtien, but there are smaller ones at other places. The plants near l'Arcahaie make the bricks used at Port-au-Prince and also ship them by boat to other parts of the country. So far as was learned, none of the factories make tile or terra cotta, nor any special kinds of brick, such as pressed brick, vitrified brick, or ornamental brick. The variety of products manufactured might therefore be somewhat increased.

A few brick factories were visited, particularly for the purpose of determining the kinds of raw materials used. These plants are described in the following pages. Samples of clays collected were tested at the ceramic station of the United States Bureau of Mines at Columbus, Ohio (G. A. Bole, superintendent), with the results given in the table on page 504.

One of the plants near l'Arcahaie, known as the Usine l'Étoile, was visited. It is said to be the largest of three plants at this locality, which is near the shore, about 5 kilometers southeast of l'Arcahaie. When this plant is running at full capacity it is said to produce from 15,000 to 20,000 bricks daily and to employ about 80 workmen. The bricks are shipped by rail to Port-au-Prince and St.-Marc and by water to other localities. They were selling in 1921 at $12 to $15 a thousand.

Alluvial clay is obtained from shallow pits about 200 meters from the shore. (See Pl. XXXVIII, *A*.) The clay is rather variegated in color, the mixture of red and white resulting generally in a brownish tinge. It consists mainly of reworked Miocene marl. Certain beds appear to contain much fine calcareous sand. Gypsum in small flakes occurs throughout the clay. Sand taken from the adjacent beach at low tide is mixed with the clay in the proportion of 1 part sand to 4 parts clay. The sand is very fine and seems to consist mostly of calcareous grains.

After molding, the bricks are dried from 4 to 10 days in large sheds (see Pl. XXXVIII, *B*) and are then burned in intermittent wood-fired kilns, the only type of kiln in use in the Republic. There are five of these

Results of tests of clays.

No.	Location.	Source.	Water of plasticity r cent).	Working quality.	Dry volume shrinkage (per cent).	Drying behavior.	Burning behavior.	Fire shrinkage.		Softening temperature (cone No.).	Color in raw state.	Color after burning.	Remarks.
								Cone No.	Per cent.				
1...	Brick factory at l'Arcahaie.	Alluvial.	35.2	Good.	35.5	Fair.	Good at cones 07, 06, 05, 04.	07 06 05 04	3.75 3.43 1.73 2.70	02	Light brown.	Buff.	Good for common ware.
2...	Brick factory at l'Arcahaie.	Alluvial clay (No. 1) mixed with 20 per cent of beach sand.	....	Good.	27.0	Good.	Good at cone 03.	03	7.6	....	.....	Buff.	Makes good brick.
3...	Brick factory at Grande-Rivière du Nord.	Residual from basalt.	32.5	Good.	47.6	Fair.	Cracked badly at cone 04.	....	....	2	Brown.	Dark brown.	Poor.
4...	Grande-Rivière du Nord.	Residual.	28.7	Good.	20.5	Good.	Good at cones 5 and 10.	8 10	6.10 6.15	16	Red.	Brownishred.	Possibly good for building brick.
5...	Grande-Rivière du Nord.	Residual.	34.5	Fair.	17.3	Good.	Good at cones 7, 8 and 10.	7 8	13.2 14.5	14	Buff.	Grayish brown.	Good for common ware.
6...	Brick factory at La Gorge on Rivière du Môle.	Miocene marl.	38.1	Good.	....	Good.	Good at cone 03; starts to crack at cone 02; cracks badly at cone 1.	03 02	21.8 21.3	....	Gray.	Gray.	No good.
7...	Rivière Guayamouc opposite Hinche.	Miocene clay.	25.4	Good.	20.7	Good.	Good at cone 02; starts to fuse at cones 1 and 2.	02 1 2	24.2 21.1 21.8	4	Buff.	Grayish brown.	Good for common ware.
8...	Mont-Organisé.	Residual from quartz diorite.	45.9	Fair.	36.3	Good.	Showed fine cracks at cones 6, 7, 8 and 10.	6 7 8 10	20.3 22.1 23.0 24.7	13	Red.	Dark brownish red at cones 6, 7, 8. Steel-gray at cone 10.	No good.

kilns, with capacities ranging from 15,000 to 30,000 bricks each. When properly burned, the bricks are buff, presumably owing to the large amount of calcareous material in the clay. When insufficiently burned they are reddish, and when overburned they become green and brittle.

Tests of the clay (sample 1, in table on p. 504) show that it has a low fire shrinkage. It burned hard at a low temperature (cone 06). The addition of sand obtained on the beach near by makes the material dry better but gives it a higher fire shrinkage (see sample 2), indicating that the sand is highly calcareous and that its use could be discontinued. This is the most satisfactory clay tested.

The brick factory of M. LaRoche, near Cap-Haïtien, operates under its former name of G. LeConte & Cie., which is stamped on all bricks. It is on the North Plain about 3 kilometers south of Cap-Haïtien, between the Port-au-Prince road and Rivière Haut du Cap. It supplies all the bricks used in the vicinity of Cap-Haïtien and ships some by rail to Grande-Rivière du Nord. In March, 1921, twelve men were employed, and the weekly output was said to be about 5,000 bricks. The selling price was reported to be $20 a thousand.

Alluvial clay of a dirty red color is obtained from shallow pits near the plant. The clay is rather silty and is poorly assorted, containing small fragments of quartz and feldspar. Purer clay probably could be obtained east of Rivière Haut du Cap, farther away from the Morne du Cap. No sand is mixed with the clay.

The bricks are molded by hand, dried in covered sheds, and burned in intermittent wood-fired kilns. One kiln has two compartments which hold about 12,500 bricks each. One compartment is emptied and recharged while the other is burning. A larger kiln, holding 70,000 bricks, was shut down when the plant was visited.

As the alluvium of the North Plain is derived mainly from igneous rocks, the clay is not so calcareous as that at l'Arcahaie and also contains more iron oxide. As a result the bricks are deep red. A sample of clay obtained from the pits for testing was lost.

At Grande-Rivière du Nord there is a small plant owned by M. Alexis Paul, which is operated intermittently as orders are received. All work is done by hand. The single kiln holds 5,000 bricks.

Residual clay from the decay of basaltic volcanic rocks is obtained on the adjacent mountain slopes. The clay is deep red, and when wet is extremely sticky. In a pit near the plant it appeared to be about 2 meters in depth, but the upper part contained so much residual gravel that it was useless. The remainder also contained small fragments of quartz and unweathered feldspar. Three parts of this clay are mixed with one part of sand obtained from the beds of small streams or from the Grande Rivière du Nord. This sand is rich in quartz.

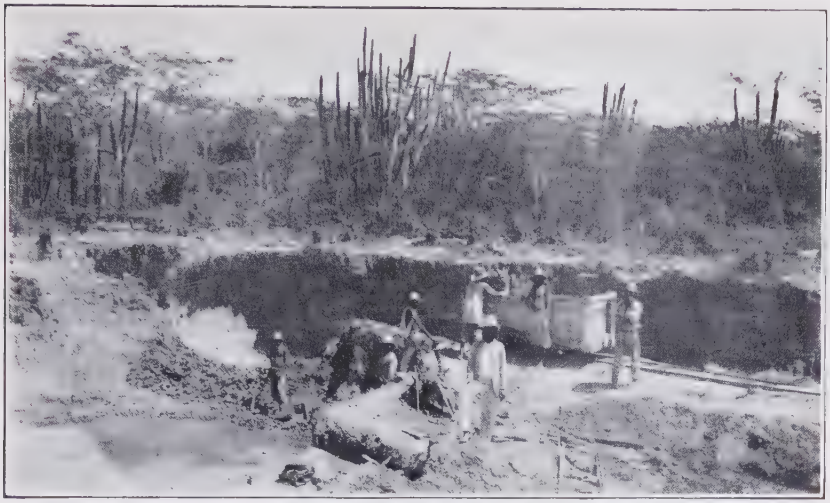
The burned bricks are deep red and resemble those produced by the plant near Cap-Haïtien. Tests were made of three samples of clay obtained at the factory and near by (Nos. 3, 4, and 5 in the table, p. 504). Sample 5 showed a rather high fire shrinkage. This shrinkage and the unsatisfactory behavior of sample 4 is avoided at the plants by adding siliceous sand. Sample 3 cracked badly at cone 04, but the other two samples made fairly satisfactory bricks, although a high temperature was necessary to burn them hard.

At La Gorge, about 3 kilometers south of Môle St.-Nicolas, a small plant had just begun to produce bricks in February, 1921. This plant was using Miocene marl resembling that for which an analysis is given on page 502 and sand from the bed of the Rivière du Môle, in the proportion of 8 parts of marl to 3 parts of sand. The sand appeared to be composed of about three-fourths calcareous particles and one-fourth fragments of volcanic rock. All work was being done by hand. The single kiln held about 5,000 bricks. When visited the plant had just finished its initial burning. Many of the bricks were cracked, but some looked fair. Tests (sample 6) show that the marl has a high fire shrinkage, and the test bricks began to crack at cone 02. The addition of sand from the bed of Rivière du Môle probably does not improve the material, as the sand is almost as calcareous as the marl.

At Hinche, in the Central Plain, a temporary brickyard was making bricks for a prison building in 1921. Loam obtained on a high-level river terrace was mixed with sand from the bed of Rivière Guayamouc. The loam deposit probably is of Quaternary age. The material is sandy and is black from organic matter, but the bricks burned red. It is said that silty clay taken from the hill leading up to the military camp made unsatisfactory bricks, but the fault may have been in the handling of the material rather than in the material itself. Tests of a sample of Miocene clay obtained near Rivière Guayamouc, opposite Hinche (sample 7), show that it makes satisfactory bricks, although the fire shrinkage is high. It burned hard at a fairly low temperature.

A sample of clay residual from quartz diorite, obtained at Mont-Organisé (sample 8), has a high fire shrinkage. A high temperature (cone 6) was necessary to burn it hard, and the product has many cracks.

Each of the factories described uses a considerably different raw material. The plant near Môle St.-Nicolas uses a consolidated marine marl, presumably very high in calcium carbonate. The tests show that this material is unsatisfactory. The plants at l'Arcahaie satisfactorily use material of the same kind which has been reworked into alluvium and probably reduced in calcareous matter. The plant at Grande-Rivière du Nord uses a residual clay resulting from the decay of basaltic rocks, and the plant at Cap-Haïtien uses material of the same kind which has been assorted and redeposited as alluvium. One other type of clay that is common in the Republic, the residual red clay resulting from the weathering



A. CLAY PITS AT BRICK FACTORY NEAR L'ARCAHAIE.

B. DRYING SHED AND KILN AT BRICK FACTORY NEAR L'ARCAHAIE.

C. PITS FOR EVAPORATING SEA WATER TO OBTAIN SALT NEAR GRANDE-SALINE.

of limestone, probably could also be used to make bricks. In general the alluvial clays are better assorted and occur in more extensive deposits than the residual clays and consequently can be worked more cheaply. Quartz sand suitable for addition to clay to reduce fire shrinkage and increase the tensile strength is found in abundance only along the streams flowing down into the North Plain. Calcareous sands have probably no value for this purpose.

SAND.

Sand is used in the Republic of Haiti mainly in lime mortar and in concrete. For these purposes sand should be graded—that is, it should consist of a mixture of grains of different sizes so that the smaller grains will fill the spaces between the larger ones. Very fine sand is not desirable, as it requires more cement or mortar and makes a weaker mixture. Sand should be reasonably free from clay and organic impurities, and particularly the surfaces of the grains should be clean, so that the mortar or cement will adhere to them readily. Good sand is scarce in most parts of the Republic, and as a result much dirty, inferior material is used. Sand is scarce because so large a part of the surface rocks are composed of pure limestone, which on weathering yields but little sand.

There are two principal kinds of sand in the Republic—calcareous sand and siliceous sand. Calcareous sand occurs to some extent along stream channels in limestone areas and is also found at some places in the Quaternary gravels. For instance, considerable sand could be screened from the gravel taken from the Cul-de-Sac Plain, of which a mechanical analysis is given on page 497. The soft coralliferous limestones of Quaternary age contain small bodies of calcareous sand at some places, and most of the recent beach sands are composed chiefly of calcareous material. As a rule all these deposits are small and irregular and contain a large amount of clayey impurities. To obtain clean sand they should be screened and perhaps also washed. An exception is the deposit of beach sand on the north coast about 4 kilometers north of Môle St.-Nicolas. This sand is composed of ground-up fragments of sea shells, reworked by the wind into dunes. It is exceedingly clean and does not contain much material more than 3 or 4 millimeters in diameter. The deposit, however, is not very large.

Calcareous sand is inferior in strength and durability to siliceous sand, but it can be used in mortar and concrete with fair results. It is of course useless for many purposes, such as for abrasives, for molding sand, or for glass making, for which purposes pure siliceous sands are required, and it is of little value for road surfacing, as it is too soft.

Siliceous sand, composed mainly of quartz, is found in large quantities only on the North Plain and along the streams in the adjacent part of the Massif du Nord that is underlain by igneous rocks. It is derived mainly from the weathering of quartz diorite. Two samples of sand from

this area were tested by the Bureau of Public Roads of the United States Department of Agriculture for use in making concrete, with results as follows:

Mechanical analyses showing fineness of two samples of sand from the North Plain.

Fineness.	Sample 1.	Sample 2.
Percentage of material passing ¼-inch screen, retained on 10-mesh.....	1	9
Percentage of material passing 10-mesh screen, retained on 20-mesh...	3	35
Percentage of material passing 20-mesh screen, retained on 30-mesh...	18	38
Percentage of material passing 30-mesh screen, retained on 50-mesh...	52	15
Percentage of material passing 50-mesh screen, retained on 100-mesh...	21	2
Percentage of material passing 100-mesh screen, retained on 200-mesh...	3	0
Percentage of material passing 200-mesh screen.....	2	1
	100	100
Loss by washing (silt and clay) in original.....Per cent....	1.5	0.5

When the sand was tested in concrete the results were as follows:

Tests of sand in concrete.

	Sample 1.	Sample 2.
Strength compared to standard Ottawa sand [a] at end of 7 days..Per cent..	64	84
Strength compared to standard Ottawa sand at end of 28 days.....do....	76	91

[a] "Standard Ottawa sand," used by engineers in the United States as a standard of comparison in testing sands for concrete, is a "natural sand from Ottawa, Ill., screened to pass a No. 20 sieve and retained on a No. 30 sieve." See Am. Soc. Civil Eng. Proc., vol. 75, p. 682, 1912.

Sample 1 was obtained from a sand bar in the bed of the Grande Rivière du Nord, at the southern edge of the North Plain, about 5 kilometers north of the town of Grande-Rivière du Nord. Quartz is the most abundant constituent, but there are considerable quantities of fragments of feldspar and limestone and some organic matter.

Sample 2 came from sand bars in the bed of Rivière Marion, about 2 kilometers west of Acul Samedi. It consists chiefly of angular quartz grains and minor amounts of feldspar, hornblende, and magnetite.

The Bureau of Public Roads states that these sands "are not as well graded as is considered necessary for first-class concrete work. Sample No. 1 is much too fine in grading to give the requisite strength for any type of Portland cement concrete construction and should not be used for that purpose. Sample No. 2 is somewhat coarser and might be used in concrete not requiring high strength, or if intended for first-class concrete construction it might be used with an additional amount of cement."

Coarser, better-graded sand could probably be obtained by searching the bed of Grande Rivière, or also from gravel pits at other places on the North Plain. Coarser sand was noted particularly near Le Trou. The deposits are extensive, and by proper screening, washing, and mixing could supply large quantities of good building sand.

Black sand derived from the disintegration of dark basaltic rock occurs in small amounts along some of the streams and more rarely on the beaches of the Southern Peninsula. A sample was obtained on the beach near the mouth of the Grande Rivière de Jérémie, where this sand is particularly abundant. It consists principally of fragments of dark basalt, augite, and magnetite, with a little calcareous sand. The magnetite constitutes perhaps 10 per cent of the sand. The screen analysis of this sand is as follows:

Mechanical analysis showing fineness of black sand from beach near Jérémie.

Percentage of material passing ¼-inch screen, retained on 20-mesh..	6
Percentage of material passing 20-mesh screen, retained on 28-mesh..	4
Percentage of material passing 28-mesh screen, retained on 35-mesh..	9
Percentage of material passing 35-mesh screen, retained on 48-mesh..	24
Percentage of material passing 48-mesh screen, retained on 100-mesh..	55
Percentage of material passing 100-mesh screen, retained on 200-mesh..	2
	100

This sand has been used in concrete at Jérémie, but the results are not known. It can not be very good for the purpose, as it is more poorly graded and much finer than either of the samples for which tests are given on page 508. If coarser, better-graded sand of this kind could be obtained it should be better than calcareous sand, although somewhat inferior to the siliceous sand.

Deposits of sand suitable for special uses demanding high purity or refractoriness, such as for glass making, molding, or the filtration of water supplies, probably do not exist in commercial quantities in the Republic of Haiti.

SALT.

Almost all the salt used in the Republic is obtained by evaporating sea water with the natural heat of the sun. This salt is highly esteemed, is cheap, and is consumed in large quantities.

Salt works are easily constructed at almost any place where there is at least a narrow strip of low land near the shore. Large works near Gonaïves, Baie de Henne, and Grande-Saline were hastily examined. At all these places the salt water is evaporated in large square or rectangular pits, generally from 30 to 50 meters long and broad and 1 to 2 meters deep. The earth excavated from the pits is thrown up around them as an embankment to protect them from surface drainage or from tidal

overflow. Many pits are constructed close together over a considerable area.

At Gonaïves, where the shore is low and flat and the soil is rather impervious, the sea water is admitted directly through open ditches, which are closed while the water is evaporating. Near Baie de Henne, however, where the pits are in a salty lagoon that is separated from the sea by an emerged beach of calcareous sand or in places by reefs of cavernous, coralliferous limestone, seepage from the sea is so effective that ditches are unnecessary. However, as the salt is deposited it tends to seal out the salt water, and after each harvest many stakes are driven into the bottoms of the pits to permit the salt water to fill them again. As more salt is deposited these holes are again sealed, and so on. A similar method is used at Grande-Saline.

When evaporation is sufficiently advanced workmen enter the pits and harvest the salt by hand, placing it in baskets. Usually it is dumped temporarily beside the pits (see Pl. XXXVIII, *C*), but if it must be stored for some time it is placed under shelter. Harvests are most frequent in the dry season, as at that time evaporation is most rapid. It is said that at Gonaïves the salt is sometimes harvested at intervals of only 18 days. As a rule, the interval is longer and may be as much as three or four months.

The salt obtained in this way is coarsely crystalline, and some of it is stained brown by impurities, but no further purification is attempted.

GUANO.

The Republic of Haiti contains numerous deposits of cave guano similar in many respects to those of other countries.[1] In 1909 the Government granted to Mr. O. P. Tommins, of New York City, a concession for the exploitation of these deposits in the arrondissements of Fort-Liberté, Grande-Rivière du Nord, Vallière, and Cerca-la-Source, notably at Cerca-la-Source.[2] The State was to receive a royalty of one-third of the product, and the valuation for purposes of taxation was placed at $1.50 per ton at the custom house, Cap-Haïtien.

The deposits occur in ordinary caves in the limestone of the mountain sides. They seem to be most common in the limestone areas of the Massif du Nord, though they doubtless occur in other parts of the Republic. The caves in the Massif du Nord are well above the level of the present streams and are now dry. The guano is formed chiefly of the excrement of bats, which inhabit certain caves in great numbers. A considerable deposit has accumulated even very recently in the abandoned workings of the old mines at Las Lomas, where bats are especially numerous.

[1] For general discussion and references see "Nitrates" and "Phosphate rock" by Clarke, F. W., The data of geochemistry, 4th ed.: U. S. Geol. Survey Bull. 695, pp. 248-253, 515-526, 1920.

[2] Le Moniteur, No. 46, p. 314, 1909.

Three caves containing deposits of guano were examined. One is about 6 kilometers southeast of Cerca-la-Source, near the Sources Chaudes de Los Pozos. (See p. 562.) Its outlet with reference to the springs is shown in Figure 35 (p. 563). There are two small openings on the hillside at an elevation about 35 meters higher than the springs. One opening has been enlarged to facilitate entrance. The openings lead downward for about 20 meters into a large chamber from which there are several radiating passages. Although there were but few bats in the cave, the air was warm and foul with the odor of ammonia. The floor of some of the passages contained patches of fresh guano and elsewhere consisted of clayey earth mixed with decomposed guano. In one of the radiating passages a hole 1.2 meters in depth penetrated entirely through the guano and clayey earth to the rock beneath. A sample of the decomposed guano mixed with clay was obtained from the floor of another part of the cave.

The two other caves examined were near St.-Michel de l'Atalaye and are more fully described in connection with fossil bones found in the cave earth which they contain (see p. 257). In the larger cave there were very few bats and little indication of guano on the floor of the cave, which was covered with red clayey earth mixed at places with loose fragments of limestone. Two pits were dug in this cave, the deeper one less than 2 meters in depth. Neither pit approached the bottom of the cave earth, which may be 10 meters in thickness. A sample of red earth was taken from the deeper pit at a depth of about 1.5 meters.

The second cave near St.-Michel de l'Atalaye is smaller. There were many bats in it, and the floor of the rear part of the cave was covered by a deposit of fresh guano several centimeters in thickness. A pit dug at one side of the cave reached the sloping bedrock at a depth of about 1.5 meters. The deposit probably is 5 or 10 meters thick in the middle of the cave. Most of the guano is badly mixed with boulders that have been washed in from the opening of the cave. No sample was taken.

Analyses of the two samples of cave earth by the Bureau of Soils of the United States Department of Agriculture are given in the following table:

Fertilizing constituents in cave earth from the Republic of Haiti.

Source and kind of material.	Nitrogen (N).	Phosphoric acid (P_2O_5).	Phosphoric acid as $Ca_3(PO_4)_2$.
	Per cent.	*Per cent.*	*Per cent.*
Decomposed guano and clay from cave near Cerca-la-Source	0.365	13.07	28.4
Red earth from cave near St. Michel-de-l'Atalaye	5.02	10.21	22.2

According to the Bureau of Soils, "The analyses of both of these materials show that they would be of value for fertilizer, one of them running especially high in nitrogen and the other in phosphoric acid."

The nitrogen in these deposits sems to be clearly derived from the bat guano, and doubtless most of the phosphate is from the same source, though a part of that in the sample from the cave near St.-Michel de l'Atalaye might be derived from bones, which were found in abundance in one part of the cave (see p. 258) although not in the excavation from which the sample was taken for analysis.

Although the guano in these caves would make good fertilizer, it is not likely that it can be exploited commercially under present conditions because the caves are so inaccessible that charges for transportation would be prohibitive, because all the deposits observed are so small that they would not supply any large quantity for export and it is doubtful whether very large deposits exist, and because the guano even in a single cave differs so much in quality from place to place through mixture with earth and stones that a product of sufficient uniformity for export would be difficult to obtain. Nevertheless, if the use of fertilizer in the Republic should become popular or necessary the deposits might be of considerable value for domestic use.

Part V. WATER RESOURCES.

By John S. Brown.

INTRODUCTION.

The need for the utilization of the water resources of the Republic is urgent. Agriculture, the principal industry, is dependent in large measure upon successful irrigation and flood control, and the principal cities are sorely in need of better and more abundant supplies of water. In addition, the development of water power is desirable to offset the lack of fuel for the generation of power.

Only a very small part of the few months spent in the reconnaissance could be devoted to a study of the water resources. The equipment available for the study was meager, and the maps at hand were wholly inadequate. The description of the water resources is therefore incomplete and poorly balanced. Some unimportant features are described in detail; other features of great importance are described briefly, for lack of further information. All the information obtained that may possibly be valuable has been given, and the suggestions offered are as practical as they can be made in view of the information available.

Considered according to their mode of occurrence, water supplies may be classified as surface water and ground water. The source of both surface and ground water is rainfall. As stated under the heading "Climate" (pp. 43-55) the mean annual precipitation ranges from about 500 millimeters on the driest lowlands to perhaps 5,000 millimeters on certain high mountain ranges. This precipitation is concentrated in two rainy seasons, which are separated by two comparatively dry seasons. The dates marking the limits of these seasons do not coincide in all parts of the Republic, and both the date and the amount of precipitation at any given locality varies somewhat erratically from year to year. A part of the rainfall fills the streams and lakes, forming surface water, some is lost by evaporation, some is taken up by plants, and a part sinks into the earth and becomes ground water, which ultimately reappears through springs and wells or seeps into streams and into the sea.

A general description of the drainage of the Republic is given on pages 32-36, and a table showing the principal streams in the order of their length is given on page 34. The streams include one large river, the Artibonite, many smaller yet considerable rivers, and a very large number of little rivers and brooks. The larger streams flow throughout the

year but are very low in the dry season. In this season many of the smaller streams are dry throughout all or a part of their courses. In the wet season nearly all the streams are subject to sudden and violent floods, for the steep and rugged slopes of the mountains that cover so large an area facilitate rapid run-off. Nevertheless, the streams are the arteries of the Republic. They supply all the water for drinking and domestic use and for stock, and they also serve to irrigate a large part of the most productive agricultural land.

There are only two large lakes in the Republic, Étang Saumâtre and Étang de Miragoâne. The water of Étang Saumâtre is brackish and unfit for domestic use or for use in irrigation. The water of Étang de Miragoâne is good, but the lake is so situated that it is of little use. The other lakes are small and of slight value as sources of water-supply. Where it is not polluted by waste and sewage, most of the surface water is good for irrigation and for domestic use. The quality of water is considered more fully on pages 542-550.

As the value of a general account of the water resources of the Republic depends mainly upon its bearing on the possibility of irrigating the more arable areas with either surface water or ground water, it seems best to give all the data relating to each area in one place. Before the Revolution the French colonists had constructed a highly developed irrigation system, using surface water, and their engineering works form the basis of virtually all the present irrigation systems. The statements here given regarding colonial irrigation are based on the work of Moreau de St. Méry.[1]

SURFACE AND GROUND WATER SUPPLY.

Although surface water is mentioned in the following descriptions, it is generally treated much more briefly than ground water, not, however, because it is of less value but because adequate data regarding it are not available.

Much more information has been obtained for the Cul-de-Sac Plain than for any other area, and as a knowledge of the conditions on this plain will assist in giving an understanding of the conditions on other plains, most of which are similar, the Cul-de-Sac Plain will be described first.

CUL-DE-SAC PLAIN.

Importance.

The Cul-de-Sac Plain has been one of the most valuable agricultural areas of the Republic, partly because of its proximity to the nation's capital and metropolis, Port-au-Prince, but chiefly because the French

[1] Moreau de St. Méry, L. E., Description topographique, physique, civile, politique et historique de la partie Française de l'isle Saint-Domingue, 2 vols., Philadelphia, 1797-98.

colonists achieved on the Cul-de-Sac Plain their greatest triumph in irrigation, as a result of which it became the most productive area in the colony except the North Plain.

Surface Features.

The principal features of the Cul-de-Sac Plain are shown in Plate XXXIX. The plain is roughly rectangular, though it is somewhat wider at the east end than at the west end. Its length from east to west is about 30 kilometers and its average width is about 12 kilometers. High mountains rise abruptly above it on the north and on the south; it is bounded on the west by the sea and on the east by the large brackish lake, Étang Saumâtre. The plain slopes in general northward almost to the very base of the Montagnes du Trou d' Eau, but its northern half is very smooth and nearly level. In the eastern part of the plain there is a low divide which extends from south to north and which turns part of the drainage westward to the sea and part of it to Étang Saumâtre. Near the middle of the northern side of the plain is a shallow depression occupied by a small fresh-water lake called Trou Caïman. This lake is said to overflow westward down the Ravine Boucan Brou when flooded. All the southern half of the plain has a pronounced northward slope and some minor irregularities of surface. Low ridges and hills break its continuity in the southeastern part.

The surface of the Cul-de-Sac Plain consists of alluvium washed down from the surrounding mountains. As the only large streams come from the south, more alluvium has been deposited on that side, and this fact accounts for the general northward slope of the plain.

The plain receives a mean annual precipitation of 800 to 1,000 millimeters, which would be sufficient to water many crops if it could be depended on and were well distributed. Unfortunately the annual precipitation varies between wide limits, and its distribution also varies considerably even in the wet seasons. Moreover, the high temperature causes great evaporation. For these reasons irrigation is necessary to insure crops, particularly of sugar cane, which is one of the plants best adapted to cultivation on the plain.

Streams and Springs.

The surface-water features of the Cul-de-Sac Plain are shown on Plate XXXIX. The principal streams watering it are the Grande Rivière du Cul-de-Sac (sometimes called the Rivière Gris) and the Rivière Blanche. Both streams rise in the heights on the south, in the Massif de la Selle, and enter the plain not far apart, near the middle of its southern border. The Grande Rivière du Cul-de-Sac flows northwest, turns gradually to the west, and flows into the sea near the middle of the western coast of the plain. The Rivière Blanche generally dries up not far from the

mountain border, but during flood it reaches the sea by way of Trou Caïman and the Ravine Boucan Brou. In the southeast corner of the plain is Rivière Creuse, a smaller stream that flows into Étang Saumâtre. It is fed by the Sources Despuzeaux and in small part by the near-by Sources Palmistes Claires. In the northeast corner of the plain is a large spring called Source Maneville, and near by is the Source Glore. Both flow into Étang Saumâtre, and Source Trou Caïman, just north of Trou Caïman, and Source Lagon, near its east end, also flow into that lake. At the northern border of the plain, near Thomazeau, is Source la Digue. In the western part of the plain springs and seepages give rise to small brooks, such as Rivière des Orangers, Rivière la Savoye, and Rivière la Boule. There are said to be some springs along the Ravine Boucan Brou, and there are perhaps others both in this region and in the eastern part of the plain, but they are probably small.

Mention should also be made of a small plain (one not shown in Pl. XXXIX) at Fond-Parisien, south of Étang Saumâtre and separated from the Cul-de-Sac Plain proper by a wide, rather high divide. This region is watered by the Rivière du Fond and certain springs near Fond-Parisien, which are included in most plans for the development of the Cul-de-Sac Plain. Some large springs in the mountains southeast of Fond-Parisien furnish water that might be available for use in this area. They are 14 kilometers southeast of Fond-Parisien, on the trail to Fond-Verrettes, about 580 meters above sea level. One is on the right fork of a stream that apparently flows into Étang Saumâtre. This spring emerges from limestone and gives rise to a stream that seems to be fully as large as the Source Maneville. The left fork of the stream has about the same volume of water. Canals to divert this water would have to be carried around a high ridge over difficult terrane.

None of the streams or springs on the Cul-de-Sac Plain is very large. The largest stream there, Grande Rivière du Cul-de-Sac, ranks low among the greater streams of the Republic. (See p. 34.) Almost all its water comes from the mountain watershed, which probably has an area of not more than 300 square kilometers. Throughout its course on the plain it loses so much water by seepage and evaporation that long stretches of its lower course are dry in the dry season, and probably were so even before its water was diverted for irrigation. The office of the Engineer in Chief has made gagings of the Rivière du Cul-de-Sac at frequent intervals since 1918. These gagings show that the ordinary flow ranges from less than 100 to more than 300 cubic feet per second, as shown in the table below. The figures for 1918 and 1919 are less reliable than those for later years, which are based on much more frequent observations. The figures given, except those for the Sources Despuzeaux, do not include the peak flow during floods, which could not be measured with the facilities at hand. The flow of the Source Maneville is probably about the same as that of

Sources Despuzeaux. The other springs of the plain are much smaller, yielding not more than a few hundred liters per second.

Flow of Grande Rivière du Cul-de-Sac (at Bassin Général) at ordinary stages.

[Cubic feet per second.] [a]

	1918	1919	1920	[b]1921
Maximum	760+	492	334	494
Minimum	100±	60	37	42

[a] The cubic foot is equal to 28.3 liters.
[b] First 9 months of 1921.

Flow of Rivière Blanche and Sources Despuzeaux, 1920 and 1921.

[Cubic feet per second.]

Rivière Blanche.			Sources Despuzeaux.		
	1920	[a]1921		1920	[a]1921
Mean	61	60	Mean	24	19
Maximum	97	107	Maximum	26	22
Minimum	42	44	Minimum	8	8

[a] At ordinary stages.

Irrigation.

The French colonists utilized all the sources of water mentioned here except the springs at Maneville and those that feed Trou Caïman, which lay too low for diversion upon the surrounding land. The statements concerning the development of their irrigation systems are taken from Moreau de St. Méry.[1]

Irrigation was begun in 1730 by diverting water from the Grande Rivière du Cul-de-Sac through a cut in the bank in its lower course. Other diversions followed rapidly and they finally necessitated a legal adjudication of water rights and a concerted plan of distribution, which culminated in the building of a diversion dam at the site of the present Bassin Général and the construction of an extensive system of canals. Work on this project was begun in 1773 and completed in 1787. About 7,988 carreaux[2] of land were served by this system.

The Rivière Blanche was first diverted in 1741 to form an irrigation system, which was completed in 1745 and operated successfully for many

[1] Op. cit., vol. 2, pp. 269-286.
[2] The exact area of the carreau at that time is difficult to determine but was probably about 0.13 square kilometer.

years. Improvements and extensions were made in 1787-88. The area served was 4,959 carreaux, but the water available was insufficient to irrigate the entire area.

The Rivière Creuse was diverted for irrigation in 1738, and the usual difficulties attending apportionment and distribution were settled about 1754. The area served was 3,620 carreaux.

The Sources Palmistes Claires and most of the other scattered springs were appropriated and used by their owners and others in the vicinity. The total area served was as follows:

	Carreaux.
From the Grande Rivière du Cul-de-Sac	7,988
From the Rivière Blanche	4,959
From the Rivière Creuse	3,620
All others (including Fond-Parisien)	3,091
	19,658

The supply of water for several of these systems is said to have been inadequate, and the area effectively irrigated is estimated at 13,000 carreaux, or about 169 square kilometers. The total area under ditches was about 255 square kilometers. The total area of the plain is about 360 square kilometers, a considerable part of which is not irrigable. The figures given indicate that the French colonists developed practically all the irrigable land in the plain and probably cultivated nearly half its total area.

The irrigation system left by the French colonists has been in use ever since the Revolution but has gradually deteriorated. It has suffered from lack of maintenance and has been damaged by earthquakes, which caused much loss of water by seepage and broken ditches. Some repairs have been made in recent years, but no coordinated system of distribution has been established. The area under effective irrigation at present is much smaller than that irrigated by the colonists. The Haytian-American Sugar Co. has developed large sugar plantations, on which it has practised irrigation effectively, but the company has had much trouble in getting enough water for its land because of conflict with the rights of other property-holders. It has therefore been forced to resort to pumping from wells to supplement its supply from the canals.

Ground Water.

GEOLOGIC FEATURES AFFECTING GROUND WATER.

The Cul-de-Sac Plain is an immense basin covered with stratified alluvium consisting of beds of coarse gravel, sand, and silt, and perhaps even some clay. These beds are made of the sediment carried by streams, chiefly by Grande Rivière du Cul-de-Sac and Rivière Blanche. The beds are not folded but generally slope gently down toward the lower parts

of the plain, where they are nearly horizontal. The coarser beds predominate at the borders of the plain, particularly the southern border, and the finer beds are in the middle and on the north side. The beds vary vertically as well as laterally, and coarser material alternates with finer material even in the center of the plain. The total thickness of alluvium is not known, but may reach 100 meters. The surficial material was deposited on land, probably to a depth of at least 30 meters; the deeper strata may be marine (see p. 521), but this difference probably makes little difference in the circulation of the ground water. The alluvium overlies a series of strongly folded Miocene beds containing soft conglomerate, sandstone, limestone, and marl. These beds are probably underlain by hard, massive limestone.

The porous beds in the alluvium, particularly the beds of gravel and sand, absorb water from rainfall, from seepage from streams, and from flood water from the adjacent mountains. The flood water, percolating downward, has filled all the porous beds of alluvium except those near the surface, which are easily drained by seepage. The porous beds in the Miocene rocks have probably also been filled with fresh water in the same manner at many places, and they may even contain water absorbed in certain areas on the flanks of the mountains that border the plain where they crop out. These beds, however, are probably not a source of much of the ground water in the plain. The depth to water or to the water table in the plain ranges from the surface to 30 or 50 meters, and is greatest on the high land at the southern border.

The geologic features described indicate that conditions requisite for flowing artesian water exist here. These conditions, as found in the plain, are (1) outcropping beds of porous sand and gravel, chiefly on the south side of the plain; (2) a dip that passes gently down toward the north; (3) overlying relatively impervious beds of clayey silt. The water contained in the porous beds beneath the lower part of the plain is therefore under hydrostatic pressure from that contained in the same beds or other connected beds at higher altitudes to the south. Flowing wells may be obtained in the lower part of the plain, as was discovered, probably more or less accidentally, by the Haytian-American Sugar Co. when it began drilling for water about 1918. The wells of this company are the only deep wells and include the only known flowing wells in the Republic.

WELLS AND PUMPING PLANTS.

Wells of the Haytian-American Sugar Co.—The locations of the wells and pumping plants of the Haytian-American Sugar Co. for which data are available are shown on Plate XXXIX, where they are designated by number. Most of the sites of these wells were examined by the writer through the courtesy of the company, by whom also the logs of wells were furnished. The logs thus furnished are here given as reported by

the drillers and must be accepted with some reservations. It is difficult to tell just what is meant by "rock," and the term "clay" probably often covers silt or clayey silt.

Non-flowing well at Peyrard.—At Peyrard a well (No. 1, Pl. XXXIX) was dug to a depth of 15 meters, where water was found. In the bottom of this well a hole was drilled to a depth of 35 meters below the surface of the ground. Water continued to stand at the original level. The log of the well is given as follows:

Log of well at Peyrard.

Material.	Thickness.	Depth.
	Meters.	*Meters.*
Sandy clay	21	21
Fine gravel and clay	5	26
Clay and fine sand	2	28
Fine sand	2	30
Fine sand and gravel	1	31
Gravel and sand	3	34
Clay and fine sand	1	35

This well is on relatively high ground at the south side of the plain, and the water table lies deeper below the surface than in any other well described. The well is said to give a good yield when pumped. The log indicates that it is entirely in alluvium. The writer did not visit the well.

Flowing well near La Morinière.—Well No. 2 is typical of the flowing wells in the lower part of the plain. It yields about 284 liters per minute with the casing projecting one meter above the ground. A view of the well is shown in Plate XL, *A*. The depth of the well is unknown but is at least 70 meters, and its log also is unknown. Near this well a well was dug to a depth of 24 meters. The material penetrated is said to have been fine sandy alluvium except for a thin bed of gravel about 4 meters below the surface of the ground. The pit being excavated at the rear of the well (Pl. XL, *A*) was about 7 meters deep at the time of the writer's visit. At 2.5 meters below the surface there was a bed of coarse gravel, 1 to 2 meters thick, which rests with marked erosional unconformity (irregular surface) on underlying sandy silt. The gravel consisted predominantly of pebbles of limestone, but contained some pebbles of chert and of basalt. The pebbles averaged from 2 to 6 centimeters in diameter.

Flowing well at La Morinière.—Well No. 3 yields a larger flow than any other well in the plain, reported to be about 1,900 liters a minute. A large earthen reservoir capable of storing the flow of the well for 36 hours has been built around it. The total depth of the well is 189 meters. It is cased to a depth of 43 meters with "8-inch" casing and below that

A. FLOWING WELL NEAR LA MORINIÈRE IN THE CUL-DE-SAC PLAIN.

The yield of this well is about 284 liters a minute.

B. SALT SPRING EMERGING FROM LIMESTONE OF SUPPOSED UPPER EOCENE AGE ON THE BEACH NEAR MIRAGOÂNE.

The tide runs in and out under the bridge at the right.

C. OUTLET OF THE SOURCES PUANTES, AT THE NORTHWEST CORNER OF THE CUL-DE-SAC PLAIN.

to a depth of 75 meters with "6-inch" casing. Drilling was completed in October, 1920. The following log is given:

Log of well at La Morinière.

Material.	Thickness.	Depth.
	Meters.	*Meters.*
Not stated	43	43
Clay	7	50
Sand	2	52
Packed sand and gravel	5	57
Clay	4	61
Rock	2	63
Sand	1	64
Clay	4	68
Rock	4	72
Sand	4	76
Rock	1	77
Clay	8	85
Rock	2	87
Clay	7	94
Clay and some gravel	24	118
Soft rock	2	120
Hard rock	1	121
Rock	8	129
Sandstone	8	137
Soft rock	11	148
Clay	13	161
Rock	11	172
Sand	4	176
Alternating clay and sand	12	188
Rock	1	189

The numerous beds of rock, many of them soft, suggest that this well probably penetrates the buried Miocene beds below the depth of 63 meters. The flowing water comes from the bed of sandstone that lies at depths between 129 and 137 meters and that was encountered at a depth of 131 meters.

Pumping plant at La Morinière.—The pumping plant at La Morinière (No. 4) is a few hundred meters east of well No. 3. Water is drawn from 6 wells, which are 15 meters apart and are said not to exceed 35 meters in depth. The natural water level is said to be about 7 meters below the surface of the ground. Water is raised by a steam-driven centrifugal pump set down in a pit 7 meters below the surface of the ground. The group of wells is said to yield about 3,400 liters a minute or 567 liters a minute per well. Some of the water is pumped into an elevated tank and used for railroad supply. An analysis of this water is given on page 544.

Pumping plant at Dessources.—The plant at Dessources (No. 5) is of the same type as that at La Morinière. Pumping is done by a steam-driven centrifugal pump set 7 meters below the surface of the ground. The pump draws from 6 wells that are 15 meters apart. Some of these wells are

much deeper than those at La Morinière, and originally yielded moderately good flows (150 to 200 liters per minute), but the pump was installed to increase the yield.

The logs of three wells at Dessources, at least two of which are at Plant 5, though one may belong to group 6, near by, are given below.

Log of well at Dessources.

Material.	Thickness.	Depth.
	Meters.	*Meters.*
Clay	8	8
Sand	4	12
Clay	7	19
Sandy clay	5	24
Clay with some gravel	25	49
Clay and coarse gravel	6	55
Clay	3	58
Hard clay or soft stone	2	60
Soft limestone	2	62
White clay	9	71
Clay and sand	36	107
Yellow clay and sand	23	130
White clay	4	134
Hard white clay	2	136
Hard clay and sand	4	140
Soft sandstone	6	146
Blue clay	26	172

The above well is cased with "8-inch" casing to a depth of 60 meters. Water was found in the sand at 8 meters but did not rise above that level. From the limestone at 59 meters water rose to the surface of the ground and the flow increased successively at 85 meters and 133 meters.

Log of well at Dessources.

Material.	Thickness.	Depth.
	Meters.	*Meters.*
Clay	9	9
Sand	2	11
Clay	7	18
Sand and clay	4	22
Clay	3	25
Coarse sandy gravel	1	26
Clay	17	43
Sand and clay	6	49
Shale	2	51
Sand	2	53
Fine sand	9	62
Clay and gravel	13	75
Soft limestone	12	87
Clay	69	156

An "8-inch" casing extends to a depth of 72 meters in this well. Below that depth the well is not cased. Water was first found at 9 meters below the surface but it did not rise in the well. Flowing water was found at 51 meters and the flow increased at 87 meters. The beds down to about 50 meters appear to correlate fairly well with those of the first well, but the soft limestone (at 87 meters) appears to lie considerably deeper than in the first well, yet it may nevertheless be the same bed if, as suspected, it is one of the folded Miocene beds. The water-bearing horizons also correlate rather closely, if the limestone in each well is the same.

Log of well at Dessources.

Material.	Thickness.	Depth.
	Meters.	*Meters.*
Clay	9	9
Sand and clay	1	10
Clay	36	46
Clay and fine sand	15	61
Clay	37	98
Soft rock	6	104
Clay	6	110
Hard packed sand	15	125
Clay	8	133
Clay and sand	7	140
Blue clay	16	156

The above well is cased to a depth of 35 meters with "8-inch" casing and below that to a depth of 52 meters with "6-inch" casing. Water was first struck at 9 meters, but the principal supply comes from a depth of about 61 meters. The absence of anything classified as limestone casts some doubt upon the correlation of this well with the first two, although the water horizons are at very nearly the same depths as the two upper horizons in the other wells.

Officials of the company were not certain of the locations of the wells whose logs are given, and probably the last one may belong to group 6.

As intimated above, it is suspected that the rocks in the first two wells from the reported bed of limestone downward are of Miocene age.

Flowing wells at Dessources.—A group of flowing wells at Dessources (No. 6) is a short distance northeast of the pumping plant (No. 5). The first well is 300 meters from the pumping plant and yields a flow of perhaps 50 liters a minute. The second well is about 200 meters farther northeast, and the third is just east of it. Both yield flows estimated at about 200 liters a second. There is a pronounced northward slope to the land here, which probably accounts for the stronger flows in that direction. The casings of all the wells protrude about 0.5 meter above the ground and are 8 inches in diameter. The depths and logs of the wells are unknown, unless perhaps the log given above is from this group.

Pumping plant at Vaudreuil.—A pumping plant was just being installed at Vaudreuil (No. 7) in April, 1921, and the pump was then not yet in operation. Six wells had been drilled at intervals of 15 meters in a north-south line beginning very close to the bank of Grande Rivière du Cul-de-Sac. All were "8-inch" wells except one, which was only 3 inches in diameter. The six wells range from 30 to 60 meters in depth. Most of them yielded slight flows, but yields of 400 to 500 liters a minute per well were expected on pumping. The pump was to be connected also with Grande Rivière du Cul-de-Sac, from which, it is said, 10,000,000 liters can be pumped daily throughout 8 months of the year. An analysis of a sample of the water from the most northerly well of the group is given on p. 544. This well flowed about 10 liters a minute at an altitude of 1 meter above the ground. A log of one of the wells is as follows:

Log of well at Vaudreuil.

Material.	Thickness.	Depth.
	Meters.	*Meters.*
Yellow clay and sand	4	4
Coarse white and gray sand	5	9
Sand and clay	3	12
Blue clay and fine sand	8	20
Blue clay and coarse sand	3	23
Blue clay and gray sand	3	26
Blue clay and fine sand	3	29
Sand and gravel	2	31
Yellow clay and fine sand	6	37
Yellow clay and coarse sand	8	45
Yellow clay and fine yellow sand	5	50

There is nothing in this log to suggest Miocene beds.

Pumping plant at Drouillard.—There is a pumping plant at Drouillard (No. 8) which is said to comprise several wells 18 to 20 meters in depth, most of which yield very little water. No logs are available.

Abandoned well at "Hasco" mill.—On the grounds where the mill of the Haytian-American Sugar Co. ("Hasco") is situated, a well (No. 9) was drilled, which yielded only a little water of very poor quality. The log is as follows:

Log of well at "Hasco" mill.

Material.	Thickness.	Depth.
	Meters.	*Meters.*
Soil, clay, and sand	20	20
Sand	3	23
Blue clay	2	25
Fine sand and clay	4	29
Blue sand	2	31
White clay and broken limestone	10	41

The last 10 meters of the material is probably of Miocene age, as Miocene beds crop out across the railroad just to the east, and the alluvium probably is not very thick at the mill site. The poor quality of water probably was due to the proximity of the well to the sea (see p. 545).

Abandoned well at "Hasco" residences.—A well (No. 10) was drilled on the hill east of the "Hasco" mill, where several of the company's officials reside. It is just beyond the edge of the plain, and Miocene beds crop out at the surface and apparently persist to the bottom of the well. Very little if any water was obtained, and the well was abandoned. The lithology of the Miocene beds penetrated in this well closely resembles that of the lower beds in wells in the plain that are supposed to penetrate Miocene beds. The log is as follows:

Log of well at "Hasco" residence site.

Material.	Thickness.	Depth.
	Meters.	*Meters.*
Conglomerate (residual)	2	2
Marl	6	8
Yellow clay	19	27
Rock	3	30
Open ground (probably soft material)	10	40
White and yellow clay	5	45
Blue clay and shale	15	60
Limestone	3	63
Blue clay	3	66
Limestone and clay	3	69
Clay with shells	3	72
Black clay	9	81
Blue clay	5	86
Shell bed	1	87
Blue shale	2	89
Limestone with shells	6	95
Limestone with corals	3	98
Limestone with corals and shells	27	125
Blue shale	10	135
Limestone	4	139
Blue shale	2	141

VALUE OF SPRINGS.

In considering ground water in the plain, the springs mentioned under sources available for irrigation (p. 515) should not be overlooked, as spring water is in reality escaping ground water. The springs mentioned may be separated into two classes, which should be distinguished. One class comprises springs that issue from caverns in the limestone and that probably represent the outlets of underground streams that are similar in some respects to surface streams. This class includes the springs north of Trou Caïman and those at Maneville and may include certain others that were not visited. These springs represent ground water that comes to the plain from the mountains and are so situated that they probably neither

contribute to nor draw from the ground water of the plain, so that they need not be further mentioned here. The second class of springs includes all those fed by water escaping from the alluvium of the plain—either overflowing the rim of impervious beds or rising under artesian pressure. It includes the springs that feed the Rivière des Orangers and Rivière La Savoye, and probably those that lie along the Ravine Boucan Brou and the Sources Puantes. It may include those that feed the Rivière la Boule and the Rivière Creuse, which unfortunately were not visited. These springs are probably fed from the large body of ground water that lies beneath the plain, and if so, they should be considered in any description of the occurrence and utilization of this ground water. Indeed, even without the confirmatory evidence of flowing wells, the existence of artesian water beneath the plain would be strongly suggested by the occurrence of these springs.

CONCLUSIONS AS TO GROUND WATER IN THE CUL-DE-SAC PLAIN.

The record of the well at Peyrard indicates, as was to have been expected, that the water table on the southern side of the plain lies well below the surface and that flowing wells can not be obtained there. This is the intake area of the artesian system and only in the lower areas, where the water is under pressure, can wells yield flows. The southern boundary of the area of artesian flow probably runs from Croix-des-Missions due westward to the sea, from Croix-des-Missions southeastward to Croix-des-Bouquets, and from Croix-des-Bouquets due eastward to Étang Saumâtre. Flows might perhaps be obtained in a small area south of this line in the area southeast of Croix-des-Missions, near Source Cazeau. Flowing wells will probably be found at some places over most of the area north of the line, at least as far as the slope of the plain continues northward. The records show that not all wells that may be drilled in this area will flow, for non-flowing wells have been obtained very close to flowing wells, and generally the shallower wells, those less than 50 meters deep, are non-flowing. These uncertainties are probably due in large part to rapid variations in the porosity of the alluvial beds. Coarse porous beds capable of yielding a strong flow in one well may thin out abruptly and be absent in a well near by, which accordingly yields no flow. Wells penetrating Miocene beds are erratic, because those beds are folded and their attitude is disturbed. The bed that yields a good flow in one well may easily dip beneath the reach of a well of like depth only a short distance away, or it may have been removed by erosion before the alluvium was laid down at the site of the second well.

It seems likely that wherever water is obtained in this lower part of the plain its level will be not more than 5 or 10 meters below the surface of the ground. Large yields can be obtained from nearly all non-flowing wells by pumping, and the yield of flowing wells can be greatly increased by pumping.

The quantity of water that can be safely drawn from flowing wells and pumping plants in the plain is strictly limited. It comes originally from rainfall on the surface of the plain and on the bordering mountain watersheds. A very great part of it comes from the mountain slopes on the south. The mountains north of the plain are semiarid and contain no permanent streams. The altitude of the plain on the north side is low, and flood water is probably prevented from penetrating the water-bearing beds partly by the pressure transmitted to the underlying water from the south and partly by the non-porosity of the surficial silts. The same factors also prevent the absorption of any considerable part of the direct rainfall over the entire area of artesian flow. The supply must therefore be obtained almost entirely from the southern mountain slopes and the southern edge of the plain. Probably most of it comes from the flood runoff from these mountains, and perhaps some is supplied by infiltration from the Grande Rivière du Cul-de-Sac, the Rivière Blanche, and irrigation ditches along the southern side of the plain. If plans for the conservation of flood water of the rivers should be carried out the available ground water in the plain would be reduced.

Any heavy drain upon the ground water of the plain by either flowing wells or pumping would probably affect the flow of the springs that are fed by seepage from the ground water beneath the plain, such as the Rivière des Orangers, Source Cazeau, and others. The lowering of the water table would probably diminish their flow or even cause them to disappear entirely. The springs that emerge from limestone and others that are found at the borders of the plain, such as those at Maneville, and probably the Sources Despuzeaux, would not be affected.

Emphasis should be laid upon the fact, so seldom realized, that flowing water can be wasted and dissipated quickly, whereas it is replaced very slowly. Flowing wells should be capped at all times when the water is not needed, just as the faucet of a water tank is closed when the water is not in use. Overtaxing of the ground water in the plain would result in a lowering of the water table to a depth where pumping would be impossible or very expensive, and in an invasion of the ground by salt water, either from the sea, to the west, or from the Étang Saumâtre, to the east.

Nevertheless, there is a considerable opportunity for the development of ground water, and it is believed that thorough and careful utilization of all the available surface water and ground water would permit the reclamation of virtually the entire irrigable area of the plain.

ARCAHAIE PLAIN.

The Arcahaie Plain is nearly continuous with the northwestern corner of the Cul-de-Sac Plain. It is a long, narrow, and rather steeply inclined coastal plain cut off abruptly by high mountains. Its length is about 28 kilometers and its maximum width is 5 or 6 kilometers. Near the base

of the mountains it is rough and strongly dissected. The mean annual rainfall of the Arcahaie Plain is less than 800 millimeters and nearly all crops grown on it require irrigation. The plain is watered by three or four small perennial streams. The principal ones are Rivière de Boucassin and Rivière de l'Arcahaie, in addition to which there are one or two small brooks. Even the two large streams go nearly dry at times.

The French colonists utilized all the streams to their full capacity, which was limited greatly by the small minimum flow. Their massive masonry aqueduct, still in use at Boucassin, is a worthy memorial to their practical skill. The plain is still cultivated intensively, and most of the normal stream flow appears to be utilized, but it is not sufficient to irrigate all the arable land of the plain. Improvements could probably be made in the distribution system, but there is not much hope of storing the flood water of the streams, for their mountain valleys are very steep and narrow and are cut mostly in limestone.

Shallow wells are used to some extent on the plain, but not for irrigation. The beds that immediately underlie the plain are alluvial. Those that lie near the mountains are coarse, those that lie near the sea are fine and some of them even clayey. The beds are undisturbed but have a normal seaward dip conforming somewhat to the slope of the plain. Beneath the alluvium lie folded Miocene beds, which dip seaward. These conditions may make it possible to obtain flowing wells in the lower part of the plain, perhaps in some of the area that stands less than 10 or 15 meters above sea level. Because of the very short slope of the plain, however, strong flows are not to be expected. Moreover, deep wells near the sea may yield salty water. Some water for irrigation could probably be obtained either from flowing wells or by pumping. Wells should not be more than 50 meters deep very close to the sea and probably not more than 150 meters anywhere in the plain.

LÉOGANE PLAIN.

The Léogane Plain is a large delta plain that is bordered on the north by the sea, from which it extends back southeastward into a prominent reentrant in the mountain ranges. It is comparatively level except near the base of the mountains, and its seaward slope is not great, although considerably more than that of the western part of the Cul-de-Sac Plain. The annual rainfall at Léogane averages about 1,150 millimeters, but irrigation is desirable for many crops.

The principal stream is Grande Rivière de Léogane, also called Rivière Momance, which is one of the larger rivers of the Republic. (See p. 34.) It flows diagonally across the plain and has been the chief agent in transporting the alluvium of which the plain is formed. According to measurements made by engineers of the Department of Public Works, during 1920 and the first 9 months of 1921, the minimum flow was about

60 cubic feet per second, and the observed maximum was 800 cubic feet per second. The peak flow during floods was not determined. Rivière des Citronniers, farther west, is a small yet considerable perennial stream. Numerous brooks and springs supply some water to the plain.

The French colonists, according to Moreau de St. Méry,[1] utilized the water of the Grande Rivière de Léogane to irrigate about 8,000 carreaux (approximately 104 square kilometers) in the plain. Irrigation was begun about 1727. A formal apportionment of water rights was made in 1737 and revised in 1787. Irrigation is still practiced on the principal agricultural holdings, and a crude diversion and distribution system is in use. Not nearly all the available water is used, and much arable land is irrigated poorly or not at all.

Valuable springs rise in at least two localities in the lower part of the plain. One locality is just north of the town of Léogane, where several springs which issue from a small depression supply water for domestic use in the town. A great part of the flow is not utilized, at least not near its source. Several kilometers northeast of Léogane but west of the Rivière Momance some large springs issue from a marshy area and feed a stream called Rivière Père, which is said to yield several second-feet of water. The ruins of old conduits indicate that this stream was utilized by the French, but the water now goes to waste. The springs that here rise from the plain show the presence of ground water that is probably under slight artesian pressure.

A few shallow wells are used, but not for irrigation. A well at the Gendarmerie barracks in Léogane, about 4 meters deep, contains water about 2 meters below the surface of the ground. Ground water undoubtedly could be obtained from wells almost anywhere in the plain, although in the higher parts it probably would lie considerably below the surface of the ground. In the lower part of the plain it should rise nearly to the surface, and some wells might even flow. Flowing wells would probably be restricted to areas that stand less than 10 meters above sea level, but good pumping wells should be obtained over a much larger area. The maximum depth of wells should not exceed 150 meters, and wells drilled near the sea probably can not be carried so deep, as they are likely to get brackish water.

The surface and ground water available should be ample to irrigate all the arable land.

CAYES PLAIN.

The Cayes Plain is smooth and has a very gentle slope near the sea but is more broken and has a considerably steeper slope farther inland. It is underlain mainly by alluvium, which was supplied by several small parallel rivers that traverse it from northwest to southeast. The largest stream, La Ravine du Sud, originates in the Montagnes de la Hotte north

[1] Moreau de St. Méry, op. cit., vol. 2, pp. 452-454.

of Camp Perrin and flows through the middle of the plain. Rivière de l'Îlet, to the east, and Rivière de Torbeck and Rivière de l'Acul, farther west, are rather large streams, and there are several smaller ones. None of these streams is very large, and in crossing the plain they go dry in some dry seasons. La Ravine du Sud, in particular, is dry for long stretches, possibly in part through the diversion of much of its water for irrigation. The mean annual rainfall at Les Cayes exceeds 2,100 millimeters, which is very high, but irrigation is necessary over a large part of the plain, particularly on the higher land.

The French colonists, according to Moreau de St. Méry,[1] utilized only a part of the available streams. The Rivière de l'Acul was diverted and apportioned in 1761. A very difficult but successful diversion of La Ravine du Sud was completed in 1770. The same canal, known as the Canal d'Avezac, is now in use and the present intake is at the same place as the old one, about 2 kilometers north of Camp Perrin. The total area of the plain is probably a little more than 200 square kilometers, about one-half of which is said to have been irrigated. A large area is still watered by the same system.

Ground water is not much used on the plain, although shallow wells are probably used at some places. The surface and underground features suggest that flowing wells might be obtained over a considerable area near the coast in the low part of the plain. The plain is underlain to an unknown depth by alluvial beds consisting of gravel, sand, and silt, and, near the sea, with some beds of clay and peat. The beds are not folded but have a gentle seaward dip. These conditions are virtually the same as those under which flowing water is obtained on the Cul-de-Sac Plain. Test wells should be at least 150 meters deep, except those drilled near the sea, where there is danger of obtaining salt water. Wells of this depth may penetrate buried Miocene or older rocks, but even the older rocks may yield considerable quantities of ground water.

ARTIBONITE PLAIN.

Surface Features.

The Artibonite Plain is the broad, level, triangular plain formed by the flood plains and deltas of Rivières Artibonite, l'Estère, and la Quinte. The continuity of this plain between Dessalines and Gonaïves is broken by several small hills and a large isolated mountain called Morne Grammont. The town of Petite-Rivière de l'Artibonite marks approximately the southeastern limit of the plain. Much of the surface of the plain is very smooth, and its fine silty soil is probably as fertile as any in the Republic. Unfortunately, it is one of the most arid areas in the Republic, as the rainfall averages only 524 millimeters yearly at Gonaïves and probably not much more over the rest of the plain. Moreover, although the region

[1] Moreau de St. Méry, op. cit., vol. 2, pp. 669-681.

is very arid, it suffers every year from floods, a great part of the most fertile land being inundated by the Artibonite and Estère during the wet season. The sediment deposited during these floods has formed the fertile soil of the plain, and the Artibonite is sometimes called the Nile of Haiti.[1] The Artibonite is by far the largest stream watering the plain, although the Estère is among the considerable smaller rivers of the Republic. La Quinte is very small and never reaches the sea except during floods.

Irrigation and Flood Control.

A little land about the borders of the plain is irrigated from small streams that flow at altitudes which permit them to be easily diverted. All the water of La Quinte is used in this way and some from the Petite Rivière and the Estère and its tributaries. The Artibonite, however, has never been successfully diverted, not even by the French colonists. Some crops appear to be grown by planting immediately after the annual floods recede, although no reliable information on this subject was obtained.

Flood control is the first essential of any plan for reclaiming the Artibonite Plain. The French colonists realized this and formulated many plans for the control of floods and the irrigation of the plain.[2] Above Petite-Rivière de l'Artibonite levees afforded complete protection, and from that point down to the "Center Ferry," somewhat below the present Pont Sondé, they gave uncertain protection. Everything below that locality was flooded yearly. From 1744 until the close of the colonial period schemes were constantly under discussion for the complete control of the river and the diversion of water for irrigation. Most of these plans contemplated diverting water at a locality called Morne de la Tranquilité, above Petite-Rivière de l'Artibonite, about halfway to Verrettes. Canals were made at this locality several times, and the work was fairly well advanced. But every effort, either at flood control or diversion of water for irrigation, was finally nullified by extraordinary floods, each one worse than the one preceding. Other plans involving the use of steam pumps to lift water for irrigation were tried, but never prospered very long. Moreau de St. Méry concludes:[3]

* * * Il faut dire, parce que c'est la vérité et avec une douleur profonde, qu'après 45 années de recherches, d'opérations, de soins, de tentatives, l'arrosement de la plaine de l'Artibonite par la rivière qui la traverse et l'égoût de ces eaux, n'existent point encore, quoique leur possibilité soit appuyée de preuves mathématiques, * * * et quoique la nécessité de cette double opération ne fasse que s'accroître chaque jour! Étrange, mais trop commune fatalité de tout ce qui est vraiment utile!

[1] Rouzier, S., Dictionnaire géographique et administratif universel d'Haïti, vol. 1, pp. 52-54, Paris, 1891.

[2] Moreau de St. Méry, op. cit., vol. 2, pp. 128-156.

[3] Idem, p. 155.

The successful execution of this project is still desirable, if practicable, although it would undoubtedly be expensive. Floods might be controlled by storing the surplus flood water or by building levees along the river. Storage is preferable if it is practicable, for it would conserve much water that otherwise would be wasted and would impound water that could be used to generate power. Some good dam sites can probably be found above Petite-Rivière (see p. 594), but it is questionable whether they would afford storage for the enormous volume of flood water. Flood control by constructing levees can be accomplished only by leaving a very wide space over which the river may expand. Perhaps a combination of the two methods would afford the most practicable plan of flood control. Control of the Artibonite must also include control of the Estère, whose floods, in expanding over its flat delta, unite near the sea with those of the Artibonite to form a continuous sheet of water.

The reclamation of the Artibonite Plain is the most difficult project of the kind in the Republic, and perhaps should not be attempted at present. When smaller undertakings of this kind have been installed and successfully maintained, it may be wise to attempt the control and utilization of the Artibonite.

Ground Water.

Shallow wells may be used occasionally, but no wells were observed in use in the Artibonite Plain. In discussing ground water it is necessary to distinguish between different parts of the plain. The main body of land—all that lying south of Rivière l'Estère—is underlain by alluvium of rather finer texture than that of the beds commonly found on the alluvial plains of the Republic, and the surface has a much gentler seaward slope. The total fall of the Artibonite from Petite-Rivière de l'Artibonite to the sea is only about 24 meters in a distance of probably 50 kilometers as the river flows. Porous water-bearing beds of alluvium doubtless underlie the plain, and water could be obtained by wells, although they might have to be sunk 15 to 30 meters. Water would doubtless rise within pumping distance of the surface over most of the area, but because of the gentle slope flowing wells should not be expected. Salt water probably underlies the fresh water for a considerable distance back from the shore, being nearest the surface, of course, at the shore. Wells drilled even 5 or 6 kilometers from the shore should not be carried to any greater depth than that at which they can obtain fresh water.

Northeast of Morne Grammont there is a lowland that is partly isolated from the rest of the plain by that mountain and by scattered hills of bedrock. The lowest part of this region appears to be a playa on which flood water stands and evaporates. The alluvium here is probably very thin at many places, and bedrock might be found near the surface. The alluvial material is rather coarse near the borders of the mountains. It may contain some water, but probably not water of good quality. In this area, along

the road to St.-Marc, about 12 kilometers southeast of Gonaïves, a well was drilled in 1920 by the Artibonite Trading Co. It is said to have penetrated several alternating strata of clay and gravel to a depth of 40 meters. Water, said to be of good quality, rose within 6 meters of the surface. No use has been made of the well.

Still farther north, in the immediate vicinity of Gonaïves, the plain is underlain by coarse alluvium and has a steeper but shorter seaward slope than that on the delta of the Artibonite. Some fresh water certainly is contained in these beds and could be obtained by pumping. Flowing wells might be obtained even close to the sea, but they might be brackish. This northern part of the plain, unlike the part farther south, probably does not receive much if any ground water by seepage from the Artibonite or the Estère, and it is supplied only by the flood run-off of the neighboring mountains and the infiltration from La Quinte and smaller brooks. This supply probably would not be sufficient to furnish a very large quantity of water for irrigation.

ARTIBONITE VALLEY.

The narrow and steep-sided valley lowland along the Artibonite from Petite-Rivière de l'Artibonite to Mirebalais is part of the Artibonite Valley. In this area there is some fertile farm land in the very narrow flood-plain of the river, much of which, however, is subject to overflow. The rest of the valley is dissected by ravines and broken by ranges of hills, so that the good agricultural land is divided into many small patches. Some of this land is irrigated from tributaries of the Artibonite by diverting water at places high enough to permit distribution by gravity, and probably the best plan for further development is to extend this practice, for most of the land is probably too broken to justify the expensive works necessary to irrigate it from the Artibonite. If dams were built in this area with a view to the reclamation of the lower plain, small areas in the valley might be conveniently served.

Structurally the valley is a deep syncline. It is underlain at most places by a considerable thickness of Miocene beds, consisting chiefly of limestone and sandy marl. Drilled wells that penetrate these beds at some places might yield flowing water but there is no information at hand by which these places may be determined. Flowing wells, if obtainable, would be restricted to very low areas, such as the flood plain of the Artibonite and the bottom of the series of parallel tributary valleys to the southwest, which are prominent features between La Chapelle and Verrettes. These parallel valleys are separated from the river flood plain by a prominent ridge of Miocene limestone. Unfortunately the areas where water is most likely to be obtainable are precisely those that have least need of it, as they are already well watered by near-by streams.

CENTRAL PLAIN.

Several large streams water the Central Plain, the principal ones being the Artibonite, which crosses the southeastern end of the plain, and the Guayamouc, which flows southeastward along the length of the plain. The Guaymouc is formed by the junction of the Canot and the Bouyaha, large rivers of the northwestern part of the plain. The Rio Macasia, coming from the Dominican Republic, enters the southeastern part of the plain to join the Artibonite. Besides these streams there are many smaller tributaries that flow down the surrounding mountain sides. Altogether these streams furnish a very large volume of water, some of which might be used in irrigating land in the plain, but most of this water is available only in the southeastern part of the plain, where the land is considerably broken and where only small areas are favorably situated for irrigation. There is much level land in the northwestern part of the plain, but only small streams are available to water it. They should be used, however, so far as possible.

During the time of the French colony the Central Plain was Spanish territory and was used mainly as grazing land. This plain was not irrigated to any great extent then and has not been irrigated much since. The moist and fertile valley bottoms produce good crops without irrigation. The average annual precipitation over the plain is probably about 1,100 millimeters, but the intensity of drought in the dry seasons causes the country to appear more arid than the large amount of precipitation would lead one to expect.

Structurally the plain is a deep southeastward-plunging syncline, the rocks dipping downward from nearly every side toward the center of the plain. (See pp. 488-492 and Pl. XXXVI, p. 488.) The rocks immediately beneath the surface are of Miocene age and consist of conglomerate, sandstone, limestone, and siltstone. At many places, especially in most of the northwestern part of the plain, these rocks are covered with a thin body of alluvium of Pliocene and Quaternary age, but they crop out around the border of the plain and in the interior of the southeastern part. The plain has a generally uniform slope to the southeast. The geology and surface features suggest favorable conditions for obtaining ground water. The coarse porous Miocene beds should absorb water about the perimeter of the plain, and this water, seeping downward along the beds into the center of the plain, would be confined by overlying less porous beds of siltstone, thus giving ideal conditions for artesian water. Strong flowing wells may perhaps be obtained in the southeastern part of the plain, especially from Maïssade to Thomonde and along the southern border of the plain. Wells drilled in the low valleys will yield stronger flows than those drilled on interstream areas. A well drilled to test the full artesian possibilities probably should be carried to a depth of at least 500 meters.

As some of the Miocene beds are of marine origin, they may possibly contain salt water that was imprisoned in the rocks at the time they

were deposited. The occurrence of salt water in a well in an area like the Central Plain, however, which is entirely isolated from the present sea, might be less serious than its occurrence in wells near the sea and directly affected by it. Salt water in wells in the plain could possibly be successfully cased out, and fresh water might be found in beds below it.

Shallow wells dug in the alluvium at some places, particularly in lowlands along the streams, would probably supply small quantities of water. In the northwestern part of the plain, however, the water table no doubt lies rather deep. A dry shaft about 25 meters deep is said to have been dug near the plantation of the United West Indies Corporation, which is about 5 kilometers east of St.-Michel de l'Atalaye.

ARBRE PLAIN.

The Arbre Plain is the small, flat lowland south and west of the Sources Chaudes, or Eaux Boynes, in the center of which stand the chapel and settlement of l'Arbre. This region probably receives an annual rainfall of less than 500 millimeters and is the most arid part of the Republic. All the permanent streams that descend from the mountains disappear at the border of the plain. Along the principal stream channels in the western part of the plain there are two or three playa lakes, which contain water during most if not all of the year. The water of these lakes is rather salty but is used for watering stock and to some extent for domestic supplies. There are other playas on the plain, most of them nearly always dry.

The French colonists apparently did not attempt irrigation here, but a crude system is now in use. During the annual rainy seasons there are usually one or two floods which spread large volumes of water over the plain, especially in the temporary playa lakes. A system of open earth ditches has been dug to distribute part of this flood water over the more fertile and accessible land, especially near the temporary playas, wherever the soil is not too alkaline. Irrigation appears to be practiced by sheet flooding. Cotton is the principal crop, but petit-mil, vegetables, and plantains are raised when water is abundant. Unfortunately the irregularity of seasonal floods causes many disastrous failures of the crops. The system of distribution could probably be improved, but there is no adequate source of water for the irrigation of any large part of the plain.

Over much of the plain there is a thin cover of alluvium, beneath which lies a thick series of Miocene beds, consisting of limestone, sandstone, and marl, which generally has a pronounced dip seaward. No wells are known in the area, and no springs except the Sources Chaudes, which are near the inland border of the plain. These springs, however, appear to afford some slight indication of the presence of water under pressure beneath the plain. (See pp. 558-562.) Fresh water could probably be obtained by deep drilled wells, and in the low parts of the plain weak flows might possibly

be obtained. Drilling might be tried to obtain a supply for the adjacent town of Anse Rouge. (See p. 591.) The water of deep wells in this area may be salty, for it is not at all certain that the original sea water in the deep beds has ever had a chance to drain away. Well water, if obtainable would not be sufficient for very extensive irrigation, as the rainfall is scanty and the recharge is probably small.

Shallow wells might possibly supply water for domestic use at some places, although no really favorable locations were noted. In the higher parts of the plain, where the alluvium is coarse and porous, the water table probably lies very deep, and in the lower areas the surficial beds are compact and probably not very porous.

TROIS RIVIÈRES VALLEY AND JEAN RABEL VALLEY.

The Trois Rivières Valley and Jean Rabel Valley include all the valley of Les Trois Rivières from Gros-Morne to Port-de-Paix, the immediate valley of Rivière de Jean Rabel, and a connecting lowland near the coast extending from Port-de-Paix to Jean Rabel. The region as a whole gets only scanty rainfall, and much of the lowland between Port-de-Paix and Jean Rabel is semiarid. The surface of the region is broken. The valleys are rather narrow and have steep sides, and the areas of level land are small and discontinuous.

The two rivers mentioned are the only large streams. Rivière de Moustique, about midway between them, is small and is usually dry during part of the year, but it is subject to terrific floods. Les Trois Rivières is the second largest stream of the Republic. Rivière de Jean Rabel flows throughout the year but is not included in the streams listed on p. 34.

The French colonists irrigated small patches of land along Les Trois Rivières, especially near Port-de-Paix, and a few small tracts near the river between Gros-Morne and Port-de-Paix are irrigated at present. No irrigation was practiced in colonial days on the lowland west of Port-de-Paix and little if any at Jean Rabel, although very fertile fields in that locality are irrigated now. The intervening lowland between Jean Rabel and Port-de-Paix was not visited by any of our party, and the statements here made regarding it are based either on inference or reports. The region is very much like the Arbre Plain with regard to its surface and underground features, but it receives somewhat more rain.

There is abundant water in Les Trois Rivières to supply all the land in its valley that is favorably situated for irrigation, and perhaps a good deal of that in the lowland to the west. The Rivière de Jean Rabel probably could serve more land, particularly by storing flood water, for which purpose good dam sites could probably be found.

The French colonists proposed a plan for diverting the headwaters of Les Trois Rivières into La Quinte in order to irrigate land near Gonaïves.[1]

[1] Moreau de St. Méry, op. cit., vol. 2, pp. 95-96.

Apparently the plan was to dam up and divert the water at a place called La Porte, between Gros-Morne and Pilate, where Les Trois Rivières passes through a steep-walled gorge that is said to be 64 meters in depth, but a rather careful survey is said to have shown that the divide into La Quinte basin was considerably higher than the gorge, and the plan was abandoned. This plan may be worthy of further investigation.

There are some shallow wells in the area, but ground water generally is not much used. The region is underlain by Miocene and older rocks that generally dip seaward, and artesian conditions probably exist at some places, but wells drilled at such places probably would not furnish large supplies.

NORTH PLAIN.

Surface Features.

The North Plain slopes very gently seaward, its altitude at the base of the mountains that border it on the south being generally from 50 to 100 meters above sea level. Although its relief is small, it has a variety of surface features, and large parts of it are considerably dissected. The best agricultural land is around Limonade and Quartier Morin and west of those places and is rather smooth, including only a few hills, which are low. Large bodies of level land are found also in the northeastern part of the plain. The annual rainfall over most of the plain probably averages 1,500 millimeters and at some places is more. This is considerably greater than the rainfall on most of the lowlands of the Republic and the difference is due to the position of the plain on the windward side of the most northerly mountain ranges.

Streams.

The North Plain is crossed by several streams that originate in the mountains to the south. The largest of these streams, named in order from east to west, are the Rivière Massacre, Rivière Marion, Rivière du Trou, Rivière Fossé, Grande Rivière du Nord, and Rivière Haut du Cap. The Grande Rivière du Nord is the only one of these that is listed among the large streams of the Republic (p. 34). In addition to the larger streams there are some smaller ones, which originate in the mountains and generally disappear on the plain. According to Moreau de St. Méry, there are also a few streams, such as the Rivière des Mapoux, that originate in springy and marshy areas on the plain.

Utilization of Water and Flood Control.

In colonial days and at present, agriculture on the plain seems to have been carried on almost entirely without irrigation. In normal or wet years the natural rainfall produces abundant crops, but dry years are

frequent and exceedingly disastrous. Irrigation probably would pay as a means of crop insurance, especially for sugar cane. Sugar was the principal crop of the French colonists, and they diverted water from nearly all the larger streams for use in turning cane mills. The Grande Rivière du Nord and the Fossé and Haut du Cap were utilized completely for this purpose by the rich sugar-raising parishes of Limonade, Quartier Morin, and Petite Anse. The largest diversion works were at the village of La Tannerie, where the Grande Rivière du Nord debouches onto the plain. So much water was diverted here and elsewhere that in 1786 the whole bed of the lower Grande Rivière du Nord was dry.[1]

All the streams of the plain fluctuate greatly in volume during the year and are subject to sudden and violent floods. The colonists had great difficulty in controlling floods, which often devastated some of the richest plantations. Long lines of levees were used, particularly along the Grande Rivière du Nord, but they were not always maintained in good condition and were frequently broken. The stream courses in the western part of the plain are unstable, as the river beds are rapidly aggraded and become higher than the surrounding land, causing the streams to shift their courses rapidly. Flood control is one of the serious problems in any plan for improving the water supply on the North Plain.

Ground Water.

Alluvial beds that dip very gently seaward underlie most of the plain. The alluvium consists of gravel, sand, and silty clay. At some places near the inland edge of the plain there is a bedrock bench. At the eastern end of the plain similar but more consolidated beds underlie the alluvium, and these also dip seaward. The depth of the alluvium in the western part of the plain probably does not exceed 100 or 150 meters, but in the eastern part the alluvium and the older Quaternary beds may reach a considerably greater thickness. As the rainfall is fairly heavy and the runoff from the adjacent mountains is copious it is virtually certain that the porous beds are saturated with fresh ground water at no great depth. The conditions in general resemble those on most of the other alluvial plains of the Republic, except that the beds which are likely to contain water are probably not so thick, at least in the western end of the plain, and the dip of the beds is more gentle. For these reasons ground water can probably be obtained in abundance, generally within pumping distance of the surface, on most of the plain, especially the western part. In fact, several shallow wells (5 to 6 meters deep) dug on the plantation of Mr. Kapham, about 2 kilometers southwest of Limonade, yield an abundance of water for stock and for cane mills. This place is well back toward the inland edge of the plain. The chances for flowing water are poorer there than in some other places.

[1] Moreau de St. Méry, op. cit., vol. 1, p. 233.

The presence of ground water that is probably under some pressure is attested by springy and marshy areas, such as give rise to the Rivière des Mapoux and the Petite Rivière du Quartier Morin, which originate far out on the plain. Flowing wells may possibly be obtained near the shore around the mouth of the Grande Rivière, but the flows will probably not be large. The only well that affords any evidence on this subject is that drilled at the Cap-Haïtien Railroad station at the mouth of Rivière Haut du Cap, which is more fully described elsewhere (p. 588). It is a small well, 25 meters deep, but at first yielded a slight flow. Better results might be had from deeper wells of large diameter, but they would have to be drilled farther from the sea, for the sea water affects somewhat the water of the well just mentioned, and the water probably would be worse if the well were drilled deeper.

In the eastern part of the plain, between Fort-Liberté and Ouaminthe, the rainfall is less, the relief is greater, and the depth to water is probably greater, so that shallow wells would perhaps be less successful. But the shore of the plain here is longer and the beds are better sorted, so that the possibility of obtaining artesian water in areas not much above sea level appears better.

MOUNTAINS AND HIGHLANDS.

Most of the mountain regions of the Republic of Haiti receive more rain than the lowland plains and valleys. Where their surface features and soil are favorable they are more likely than the plains to produce crops without irrigation; indeed, irrigation would be quite impossible at most places in the highlands on account of their rugged surface. Water is needed mainly for domestic use and for stock and generally is obtained from streams or springs. Some of the mountain regions receive but little rain and are semi-arid; and large areas in the regions underlain by limestone have subterranean drainage, so that the scarcity of water causes the land to be almost uninhabited. Examples of these conditions can be found in the region of Grands-Bois; in Section Plymouth, southeast of Jérémie; on the Bombardopolis Plateau; and on Gonave and Tortue islands.

Not much of value can be recorded about the streams of the mountain areas, and the geology is at most places so complicated that only a few generalizations regarding ground water can be based on the hasty observations made. The springs, which are common and at many places valuable, are described on pages 550-566.

Many of the mountain ranges are composed of hard limestone, which is generally considerably folded and disturbed and overlies igneous rocks that are exposed at many places, chiefly in the center of the ranges and in valley bottoms. Water circulates freely in the limestone through joints and along bedding planes, many of which have been greatly enlarged by solution, which has at some places formed large caverns. A large part

of the rainfall on the limestone areas is absorbed and sinks rapidly downward along these channels until its flow is checked, either by striking some less pervious material, such as igneous rock, or by reaching a permanent water table controlled by the sea or by a lake or large stream. At some places beds of chalk or of clayey partings in the limestone act as impervious beds. The water tends to move laterally down the slope of the water table or along the surface of the impervious bed until it reaches an outlet into a stream or into the sea, generally through springs.

In most limestone areas the surface is greatly dissected and the rocks are porous so that the water table undoubtedly lies very deep. Moreover, much of the ground water is concentrated in subterranean streams along solution channels. At many places in the highlands, therefore, wells would not reach water except at great depth, unless they accidentally penetrated channels of circulation. Some of these channels are indicated by sinkhole valleys, especially where surface streams disappear into sunken valleys or springs issue from them. Wells drilled in these sunken areas in regions where water is greatly needed might tap large supplies at no great depth. A suggestion for exploration of this kind at the town of Pestel is given on page 592. In regions where the cover of limestone is thin water might be obtained by wells drilled to the impervious rocks below and tapping the water that circulates along the contact of the limestone with the impervious bed. Considerable supplies of water have been obtained from such wells on the island of Barbados,[1] where conditions, however, are rather less complicated than those in most parts of the Republic of Haiti. A part of the Bombardopolis Plateau might possibly offer opportunity for work of this kind, as the porous limestone that lies above the impervious beds appears to be rather thin at some places.

Water circulates much less freely in the igneous and metamorphic rocks than in limestone because these rocks are denser and the principal open spaces in them are small joints, which are enlarged only very slowly, if at all, by solution. Moreover, these joints generally become closed at depths of a few hundred meters. The residual soil and the upper part of these rocks, however, usually absorb considerable water, which seeps down the hillsides and concentrates beneath the valleys. Shallow dug wells in valleys or ravines, or even on flat uplands in areas of igneous rock, would generally yield plenty of water for domestic use and for stock, and deeper drilled wells would be equally or even more successful, although they probably would not yield so much water as is obtained from many similar wells in the alluvial plains.

GONAVE ISLAND.

With the exception of small patches of alluvium, the only surface rock on Gonave Island is limestone. The limestone is not strongly folded, as it

[1] Harrison, J. B., and Jukes-Browne, A. J., Geology of Barbados, pp. 60-62, published by Barbadian Legislature, 1890.

is so commonly elsewhere, but has a gentle anticlinal arching. Over most of the island open textured and very porous limestone of Miocene age is the surface rock. Beneath this limestone lies similar limestone of Eocene age underlain by less porous chalky limestone, which forms a dissected plateau in the southeastern part of the island. Near the outer edge of this plateau the Miocene limestone rests directly on the chalky limestone. (See Fig. 8, p. 138.)

As might be expected from the geology, most of the drainage is underground and there are no through-flowing streams on the island. There are some springs in the southeastern part of the island, most of which issue at the contact of the porous Miocene or Eocene limestone with the less pervious chalky limestone. The largest is that in the ravine near Picmi. Another is in a ravine southwest of Anse-à-Galets. The water of both these springs disappears in the ravine beds a short distance from its source. The spring at Grande Source, southwest of Étroit, was not examined but is probably of the same type. There is said to be a spring at La Source, on the coast in the northwestern part of the island, but no details about it are known.

In the western part of the interior plateau, where chalky limestone crops out in ravines, water is obtained at several localities from shallow wells dug in the beds of ravines. Such wells were seen at Grande-Ravine, Fond Nègre, and Citadelle. Water could probably be obtained in this way along the ravines at any place where chalky limestone is exposed. Such wells should be guarded carefully from pollution. Small hand pumps would afford a very convenient means of raising water to the surface.

The northwestern part of the island is a plateau underlain by the porous Miocene limestone, and the only fresh water obtained in the interior is that which collects in holes in the bare rock surfaces during rains. This water is carefully stored for use in the dry seasons and is supplemented by brackish water carried for long distances from shallow wells along the coast. The water table in this region probably stands not far above sea level, and wells would have to be 150 to 300 meters deep to reach water. The expense of such wells would not be justified by any reason now apparent, as this region is thinly inhabited.

Wells are sometimes dug along the shore in the beach deposits or in the narrow belt of alluvium that fringes the limestone at some localities. It is said that water from some of these wells is brackish but is used for lack of better water. At some places along the shore there may be salty springs which might perhaps be improved by tapping them farther from the sea as has been suggested for Baie de Henne. (See p. 590.)

TORTUE ISLAND.

Little information was obtained about water on Tortue Island. Most of the island is underlain by porous Oligocene limestone in which underground drainage is developed, and water is therefore scarce. Beneath

the limestone lie metamorphic rocks, which are exposed in some of the valleys, particularly near La Vallée and along the coast. Springs issue along the contact of the limestone with the metamorphic rocks at the head of the valley north of La Vallée and give rise to a short stream. The largest spring seen is about 2 kilometers north-northwest of La Vallée at an altitude of 170 meters above level, where a concrete basin to impound the water was constructed by the company that proposed to exploit the forests of the island. Similar but smaller springs were seen farther east along the south coast, between La Vallée and Pointe des Oiseaux.

Moreau de St. Méry,[1] with his usual care, gives full descriptions of all the known sources of fresh water on the island. On the south coast there are spring-fed streams similar to those of La Vallée at Cayonne, about 2,000 meters west of Basse Terre and just west of Pointe des Oiseaux, as well as two smaller ones between Pointe des Oiseaux and La Vallée. There is said to be a stream on either side of Pointe Tête de Chien on the north coast. Both streams flow for only short distances in deep gorges, and disappear before reaching the sea. On the south coast at Pointe Masson, about 2,400 meters east of Basse Terre, a spring issues from a steep sea cliff. Its outlet is covered at high tide but exposed at low tide, when fresh water is obtainable.

Well water probably could be obtained by shallow wells at places in the ravines where the metamorphic rocks are exposed. There is not much hope of obtaining water easily in the interior of the island.

QUALITY OF WATER.

GENERAL FEATURES.

Most of the waters of the Republic are of good quality for domestic use when not polluted by sewage or waste. They are also generally good for irrigation and for many industrial uses. There are, however, notable exceptions to this general rule, particularly for the water from a few salt lakes and certain springs. As the rocks of a large part of the Republic are calcareous the characteristic feature of most of its waters is hardness, chiefly in the form of calcium bicarbonate. Twenty samples of water from the Republic were recently analyzed in the United States Geological Survey. These samples probably represent most of the available types.

STREAMS, FRESH LAKES, AND COMMON SPRINGS.

The following analyses cover the waters of two large rivers, the largest fresh-water lake, and five springs of the more common type. They represent by far the greater part of the water in use.

The total solids in all these waters are moderately high. The main difference between the spring waters and the surface waters is that the spring waters are generally a little more highly mineralized. Hardness

[1] Op. cit., vol. 1, pp. 733-739.

Analyses of waters from streams, fresh lakes, and common springs.

[C. S. Howard, analyst, except for Port-au-Prince supply.]
[Parts per million.]

	R. Cul-de-Sac at Bassin Général.	R. Artibonite at Pont Sondé.	Étang de Miragoâne at Pont de Miragoâne.	Gonaïves supply, home of B. F. Knighton.	Cap-Haïtien supply, Justinien Reservoir.	Port-au-Prince.		Source Maneville.
						Source Turgeau.	Source Plaisance.	
Total dissolved solids	180	218	253	225	271	278	282	370
Silica (SiO_2)	34	37	34	22	44	15	21	119
Iron (Fe)	.11	.09	.19	.15	.13	.13	.08	.14
Calcium (Ca)	23	53	51	58	39	80	92	38
Magnesium (Mg)	7.2	7.2	11	2.9	19	6.4	3.7	21
Sodium and potassium (Na+K)	26	7.6	10	18	31	[a]8.6	[a]5.4	37
Carbonate radicle (CO_3)	9.6	11	.0	.0	12	.0	.0	19
Bicarbonate radicle (HCO_3)	127	176	185	188	214	280	287	209
Sulphate radicle (SO_4)	8.6	8.4	10	5.3	10	5.5	4.9	13
Chloride radicle (Cl)	4.0	5.0	24	19	22	6.5	6.2	34
Nitrate radicle (NO_3)	.50	.38	.58	3.8	.66	Trace	9.0	Trace
Total hardness as $CaCO_3$[a]	87	162	173	157	175	226	245	181
Date of collection	Apr. 12, 1921	Dec. 8, 1920	Apr. 10, 1921	Mar. 30, 1921	Feb. 21, 1921	Jan. 31, 1919	Jan. 31, 1919	Apr. 3, 1921

[a] Calculated.

in the form of calcium bicarbonate is preponderant. The remaining mineral content consists chiefly of silica and alkali chloride and sulphate, all of which are rather low except in the Source Maneville, which, from causes not determined, is somewhat divergent from the type. All the waters are pleasant to the taste and suitable for domestic use or for irrigation. They readily form incrustations of precipitated $CaCO_3$ in pipes and conduits and in steam boilers, and so give some trouble in city supplies and in certain industrial operations. The treatment of water for the removal of hardness is considered on pages 575-576.

WELLS.

Four samples of water from comparatively deep wells, three of them belonging to the Haytian-American Sugar Co. on the Cul-de-Sac Plain, were analyzed and the results are given in the following table.

Analyses of well waters.

[Parts per million. C. S. Howard, analyst.]

	Group of drilled wells at La Morinière. (See p. 521.)	Group of drilled wells at Dessources. (See p. 523.)	Drilled well at Vaudreuil. (See p. 524.)	Well of Railroad Co. at Cap-Haïtien. (See p. 588.)
Total dissolved solids	468	423	1027	875
Silica (SiO_2)	57	69	102	41
Iron (Fe)	.07	.07	.13	.08
Calcium (Ca)	62	56	14	22
Magnesium (Mg)	27	32	26	31
Sodium and Potassium (Na+K)	60	41	325	279
Carbonate radicle (CO_3)	6.0	14	58	26
Bicarbonate radicle (HCO_3)	339	292	220	531
Sulphate radicle (SO_4)	39	54	123	13
Chloride radicle (Cl)	47	32	328	175
Nitrate radicle (NO_3)	1.5	1.3	Trace	.57
Total hardness as $CaCO_3$ (calculated)	266	272	142	182
Date of collection	Oct. 15, 1920	Oct. 13, 1920	Apr. 11, 1921	Feb. 23, 1921

The first two analyses represent normal ground water of the Cul-de-Sac Plain. They do not differ greatly from the waters of streams and springs described above except that they are a little more highly mineralized. Bicarbonates of calcium and magnesium, producing hardness, are the chief features of these waters, and probably would be the chief features of most well waters, deep or shallow, in the Republic, except those found in areas of igneous rock or at places near the shore line.

The last two waters are very different. The total solids are much higher—high enough to impart a slight taste to the water—although both waters are regarded as good for drinking. The predominant salts are alkali chlorides and sulphates, and the water from the well at Cap-Haïtien

apparently contains considerable alkali carbonate. Calcium is quite low and magnesium is in excess of calcium, a relation very unusual in normal ground waters and suggestive of sea water. Both these wells are near the sea and the high salinity is probably due to a small amount of sea water. In the well at Vaudreuil this sea water may be connate water that escapes from buried marine beds in which it was included, rather than sea water that has entered by infiltration, for the shore is a kilometer or more away, but it might also come by diffusion from underlying salt water, which may extend back a considerable distance beneath coasts.[1] In the well at Cap-Haïtien the presence of marine salts is probably due to direct infiltration or diffusion, as the well is on a sandy beach only a few meters from the sea. Ground waters of this type, contaminated by sea water, are probably not uncommon in a narrow zone along the whole coast.

SALT LAKES.

The largest saline lake is Étang Saumâtre, at the eastern border of the Cul-de-Sac Plain. Besides this lake there are a few small salt lakes of the desert playa type. The only one for which analysis is available is Étang Bois-Neuf, between St.-Marc and Mont-Rouis. The salinity of Étang Saumâtre closely resembles that of sea water, and for purposes of comparison an average analysis of sea water is given. An analysis of water from Lago de Enriquillo, Dominican Republic, which is of the same type, is also given.

Analyses of water from salt lakes and comparison with sea water and with water of Lago de Enriquillo, Dominican Republic.

[Parts per million.]

	Étang Bois-Neuf.[a]	Étang Saumâtre.[a b]	Sea water.[c]	Lago de Enriquillo Dom. Rep.[d]
Total dissolved solids	29,464	7,432	35,000	48,902
Silica (SiO_2)	48	26	.....	.....
Iron (Fe)	.07	.48	.....	.....
Calcium (Ca)	446	94	419	1,649
Magnesium (Mg)	589	279	1,304	378
Sodium (Na)	8,349	2,159	10,707	15,973
Potassium (K)	80		387	503
Carbonate radicle (CO_3)	40	46	72	.0
Bicarbonate radicle (HCO_3)	98	161	.....	512
Sulphate radicle (SO_4)	14,580	711	2,693	3,833
Chloride radicle (Cl)	4,582	3,660	19,352	25,547
Nitrate radicle (NO_3)	Trace	Trace	.....	.....
Date of collection	Dec. 8, 1920	Apr. 3, 1921	1873-1876	May 29, 1919

[a] C. S. Howard, analyst.

[b] Collected about 500 meters offshore near Maneville.

[c] From U. S. Geological Survey Water-Supply Paper 258, p. 82, 1910, after Dittmar.

[d] A geological reconnaissance of the Dominican Republic, p. 191, Washington, 1921. Analyzed by A. T. Geiger.

[1] Brown, John S., A study of coastal ground water: U. S. Geol. Survey Water-Supply Paper. (Awaiting publication.)

The water of Étang Bois-Neuf is of a type unusual in the Republic. Although nearly as concentrated as sea-water, it differs from it greatly, especially in possessing much higher sulphate and much lower chloride. Apparently its mineralization is due to concentration by evaporation. The high sulphate may be due to the presence of gypsum in the surrounding Miocene rocks (see p. 512), but if so, the calcium salt has in some way been converted into an alkali sulphate.

The water of Étang Saumâtre has about one-fifth the concentration of sea water, in striking contrast to that of Lago de Enriquillo, which is 40 per cent more concentrated than sea water. The resemblance of type is better illustrated by the following comparison of mineral constituents in terms of percentage of their sum.

Comparative percentage composition of water of Étang Saumâtre, water of Lago de Enriquillo, and average sea water.

	Étang Saumâtre.	Lago de Enriquillo.[a]	Average sea water.[b]
Calcium (Ca)	1.8	3.4	1.2
Magnesium (Mg)	4.0	.8	3.7
Sodium and potassium (Na+K)	30.6	34.2	31.8
Carbonate radicle (CO_3)	1.8	.5	.2
Sulphate radicle (SO_4)	10.1	8.0	7.7
Chloride radicle (Cl)	51.9	53.1	55.4
Total	99.7	100.0	100.0

[a] From A geological reconnaissance of the Dominican Republic, p. 191, Washington, 1921.
[b] From Clarke, F. W., Data of Geochemistry, U. S. Geol. Survey Bull. 695, p. 123, 1920.

Both these waters closely resemble sea water, although they differ from it in some details. The water of Lago de Enriquillo corresponds with sea water more closely in respect to sodium and potassium, chloride and sulphate, but that of Étang Saumâtre corresponds much more closely with sea water in respect to calcium and magnesium.

During early Quaternary time the sea occupied all the trough from Port-au-Prince Bay to Neiba Bay, separating the island of Haiti into two major parts and covering the region that is now occupied by both salt lakes. The salt water of these lakes may be residual sea water, or it may be derived from residual sea water that was held in the depressions when the land emerged. Condit and Ross[1] suggest this explanation for the salinity of Lago de Enriquillo and cite evidence to show that the shrinking of that lake in historical times by evaporation has been sufficient to account for much of its concentration. Dilution rather than concentration would have to be inferred to account for the composition of

[1] Condit, D. D., and Ross, C. P., in A geological reconnaissance of the Dominican Republic, p. 191, Washington, 1921.

Étang Saumâtre. Dilution might have actually occurred either by flooding until the lake overflowed or by an increase in the size of the basin after its emergence, as, for instance, by the building up of the alluvial barrier in the Cul-de-Sac Plain, to the west. The concentration of Étang Saumâtre could hardly have been diminished by the precipitation of material, for the ratio of mineral constituents could not have been preserved in that process. Again, it must be observed that high salinity in both lakes could probably be due to the leaching of salt beds in the rocks about their borders. Such beds of salt crop out along the southern border of Lago de Enriquillo and may occur in the vicinity of Étang Saumâtre. Finally, it is well known that many interior lakes have a mineral content which closely resembles that of sea water, although there is no possibility that they have been recently connected with the sea.[1] On the whole, it seems best not to render a verdict regarding this interesting problem until better data on the surface features and geologic history of the region are available.

MINERAL SPRINGS.

Several springs of the Republic yield water that is divergent from the more common types either in mineral content or in origin. Those for which analyses are available are considered under individual descriptions of the springs.

GRAPHIC COMPARISONS OF ANALYSES.

The relative concentration and composition of the mineral constituents in waters may be shown more effectively by charts than by mere comparisons of figures. A number of charts covering all the types of water previously described are given in Figures 32 and 33.

In constructing these charts the mineral constituents are separated into bases and acid radicles. The principal bases are calcium (Ca), Magnesium (Mg), sodium (Na), and potassium (K). Iron (Fe) and aluminum (Al) may occasionally act as bases, but are commonly regarded as present in colloidal form. Moreover, the quantity is usually insignificant and they are ignored in the charts. The principal acid radicles are carbonate (CO_3) and bicarbonate (HCO_3), sulphate (SO_4) and chloride (Cl). Silica, which may sometimes act as an acid radicle, is generally present in water in colloidal form. Its quantity, however, may be large, and it is accordingly plotted separately, as an inert constituent.

The values plotted in Figures 32 and 33 are reacting values, which are obtained by the following formula:

$$\text{Reacting value} = \frac{\text{Parts per million} \times \text{Valence}}{\text{Atomic weight}}$$

[1] Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 695, pp. 152-174, Washington, 1920.

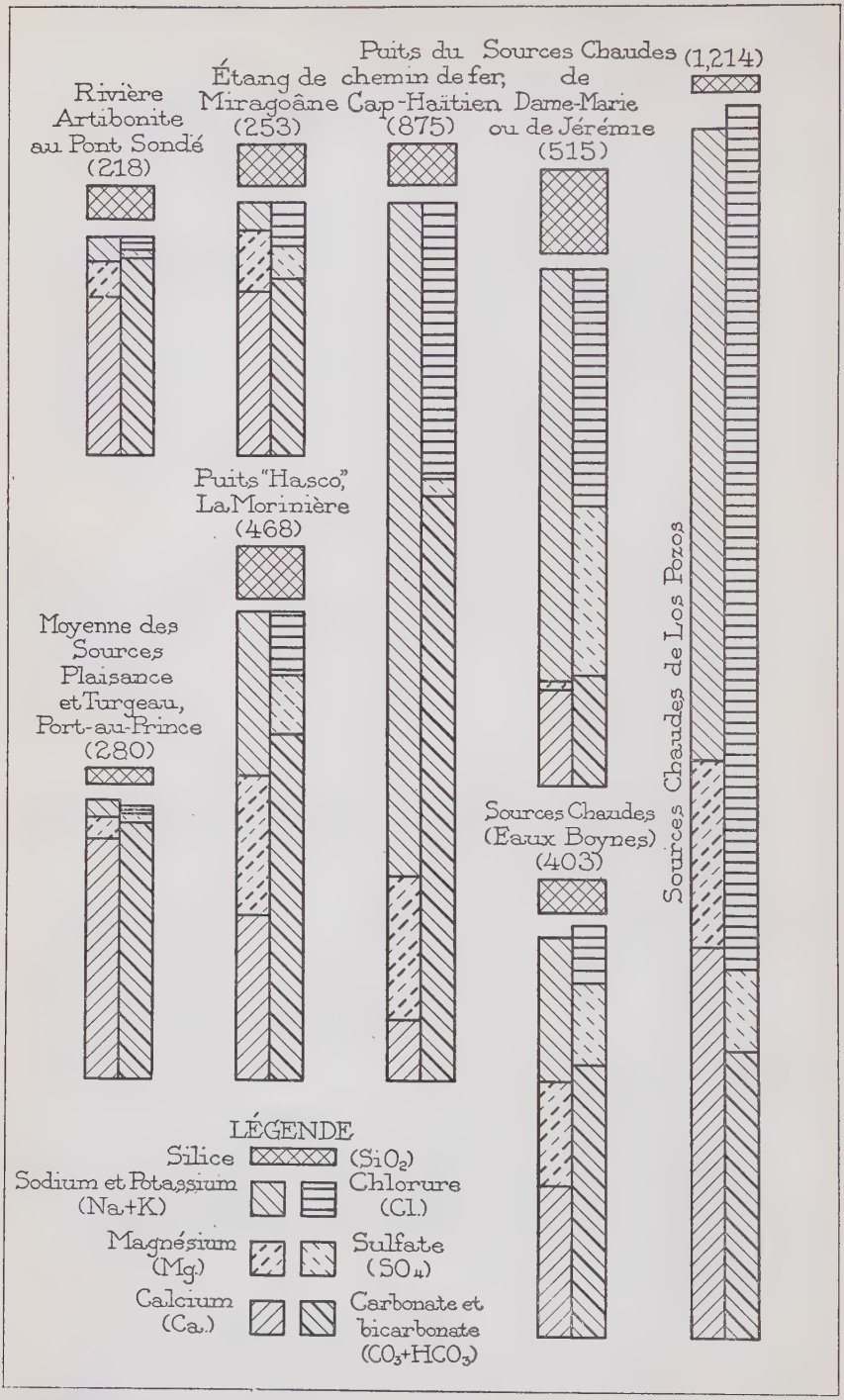

Rivière Artibonite au Pont Sondé (218)
Étang de Miragoâne (253)
Puits du chemin de fer, Cap-Haïtien (875)
Sources Chaudes de Dame-Marie ou de Jérémie (515)
Sources Chaudes de Los Pozos (1,214)
Puits "Hasco," La Morinière (468)
Moyenne des Sources Plaisance et Turgeau, Port-au-Prince (280)
Sources Chaudes (Eaux Boynes) (403)
LÉGENDE
Silice (SiO_2)
Sodium et Potassium (Na+K)
Chlorure (Cl.)
Magnésium (Mg)
Sulfate (SO_4)
Calcium (Ca.)
Carbonate et bicarbonate (CO_3+HCO_3)

FIGURE 32.—Graphic representation of analyses of some waters of the Republic.

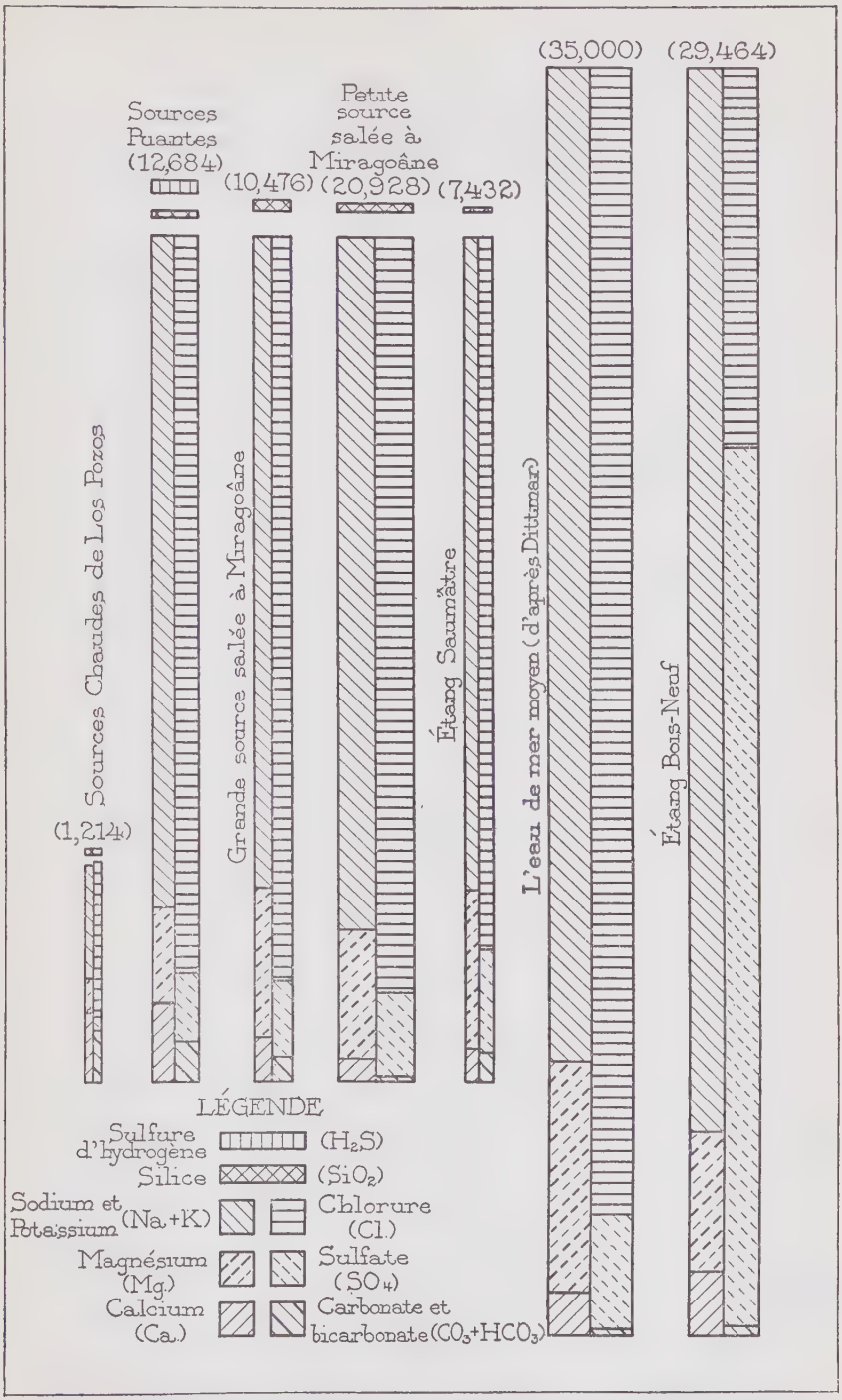


FIGURE 33.—Graphic representation of analyses of some waters of the Republic.

Scale greatly reduced as compared to Figure 32; for relative scale compare representation of the Sources Chaudes de los Pozos in both figures.

The factor $\frac{\text{Valence}}{\text{Atomic weight}}$ is called the reaction coefficient.[1] In any stable chemical system the acid radicles must balance the bases, and their reacting values should, therefore, be equal, and this fact is evident in most of the charts. Slight discrepancies may be explained either by the presence of small quantities of undetermined constituents or by minor errors in the analytical results.

In the charts shown in Figures 32 and 33 the large areas in which the acids are plotted against the bases are proportional in size to the quantity of mineral matter—the total dissolved solids. The scale in the two figures is different, however, as is shown by comparing the sizes of the two areas for the Sources Chaudes de Los Pozos. The height of the area shown for silica is based upon the ratio of the reacting value of silica to the sum of the reacting values of both acids and bases.

The charts bring out forcibly the features of the different types of waters described. The surface waters, represented by Rivière Artibonite and Étang de Miragoâne contain the lowest total solids, the common springs, represented by the Port-au-Prince supply, slightly more, but the character of all three is much the same, high calcium carbonate being the principal feature. The wells at La Morinière contain higher total solids, relatively less calcium, and more magnesium, as well as more silica.

The type of water in the well of the railroad company at Cap-Haïtien is unusual. Calcium is very low, magnesium is higher than calcium, and sodium and potassium are very high and are present largely as carbonate.

The similarity of the water of Étang Saumâtre to sea water and the dissimilarity between the water of Étang Bois-Neuf and sea water are very evident in the graphic comparison in Figure 33.

The remaining charts cover unusual spring waters considered under the heading "Springs" (pp. 553-566).

SPRINGS.

GENERAL FEATURES AND CLASSIFICATION.

Springs are found at many places in the Republic, both in the mountains and on the plains, although they are uncommon in certain small areas, as, for instance, in much of the Northwest Peninsula and on Gonave Island. Springs may be classified as hot or cold, highly mineralized or not, and in many other ways. A recent and useful classification, proposed by Bryan,[2] is based on the source of the water and the structural feature that brings it to the surface. The source of the water of most of the springs of the Republic is rainfall that has entered the ground and thus become ground water. Examples of nearly all the structural types of

[1] Stabler, H., The industrial application of water analyses: U. S. Geol. Survey Water Supply Paper 274, p. 167, 1911.

[2] Bryan, Kirk, Classification of springs: Jour. Geol., vol. 27, pp. 522-561, 1919.

springs could probably be found, but only the commonest and most useful types are here described, and appropriate examples of each type are given. A few of the more noted or unusual springs are described in detail.

SPRINGS EMERGING FROM SOLUTION CHANNELS IN LIMESTONE.

One of the commonest and most useful types of springs includes those that form the outlets of underground streams that follow solution channels in limestone. Most of these springs issue at the base of mountains—either in valleys or at the border of plains—or on the sea shore. Some of them give rise to large streams, such as the Rivière Salée, near Baradères. The openings from which some of them come are visible. A good example is the Source Moreau, at the northern edge of the Cayes Plain, which issues directly from a limestone cliff and gives rise to the Rivière de Torbeck. The opening, however, is generally obscured by a mass of soil and débris, through which the water must force its way. Source Diquini (p. 571) of the Port-au-Prince supply and Source Cinq Carreaux (p. 583) of the Cap-Haïtien supply are springs of this kind; before they were cleared out and utilized they issued from a mass of soil in ravines, but the removal of this mass exposed the open channels in the rock from which the water issues. One of the largest springs of this type is the big spring at Maneville, on the edge of Étang Saumâtre. Although its opening is filled with soil it is no doubt the outlet of an underground stream that comes from the limestone mountains to the north. Sources Le Clerc and Chaudeau (p. 571), of the Port-au-Prince water supply, and Source la Pierre, which furnishes the water of Gonaïves, are other springs of this type. In fact, nearly all the springs in limestone regions are of this type, although many of them could also be classified as contact springs.

CONTACT SPRINGS.

Contact springs are of several different kinds, but all of them occur along the contact of a porous rock with a less porous or impervious rock, usually at places where the porous rock is on top. Water absorbed by the porous rock passes downward until its movement is checked by the impervious rock, and then moves laterally down the slope of the impervious rock until it finds an outlet on some hillside or in a ravine or valley. Many such springs occur along the contact of porous limestone with underlying impervious igneous rock, slate, or compact chalky limestone. Such springs also belong in the class of springs that emerge from solution channels in limestone, the solution channel having been localized along the contact with the impervious rock. A very good example is Source Cinq Carreaux, of the Cap-Haïtien water supply (p. 583), already mentioned. This spring issues at a contact between limestone and underlying metamorphic clayey chert. The springs on Gonave Island (p. 541), occur at the contact of porous limestone with compact chalky limestone, and

the springs of La Vallée on Tortue Island occur at the contact of limestone with impervious metamorphic rocks.

In regions underlain by igneous rock small springs or seeps on hillsides are rather common. Most of them are fed by water that slowly seeps from accumulations of residual soil and débris and that moves down the hillside above or upon the surface of the denser, less pervious unweathered rock beneath. Few such springs are large. An exceptionally large spring of this type is Source Belair, of the Cap-Haïtien supply (p. 584).

Contact springs of another class occur in the beds of ravines or stream courses that are dry almost throughout the year. They are commonest in semiarid regions. Most of these stream beds contain deposits of porous gravel and sand. Water absorbed by these deposits at times of flood continues to seep downstream after the surface water has disappeared. Here and there the water may meet obstructions, such as outcropping ledges of underlying impervious rock or beds of impervious clay. These obstructions force the water to rise to the surface and suggest the name "rock-dam springs," which is frequently applied to springs of this type. A good example is the spring at Terre-Neuve that supplies most of the water used in the town. This water rises from gravel that lies upon impervious igneous rock and sinks away again in the gravel farther downstream. The water reappears about 2 kilometers west of Terre-Neuve, where igneous rock and limestone are exposed in the stream bed, and flows for a considerable distance. Another example is Source Plaisance (p. 572), of the Port-au-Prince supply, which rises at a place where the alluvial gravel of the stream bed is interrupted by beds of impervious Miocene marl.

Another type of contact spring, somewhat more difficult to recognize, probably occurs on the alluvial plains and valleys, about the perimeters of artesian areas. We have seen (p. 519) how artesian water receives its head by passing downward along a porous bed beneath a confining impervious bed. When the porous bed is fully saturated the excess water absorbed at the intake area must escape, and it frequently does so through springs at outcrops of the impervious confining bed. The springs at the north side of the town of Léogane are probably an example of this type of spring, and perhaps also some of the springs on the Cul-de-Sac Plain, the Cayes Plain, and the North Plain.

ARTESIAN SPRINGS.

The type of spring last described is difficult to distinguish from the artesian spring that is due to artesian pressure and that emerges through some break or weak spot in the confining bed above. Many such breaks are produced by faulting, the water under pressure finding its way to the surface along the fault plane. Springs of this class may perhaps be found at some places in the Republic, especially on the Cul-de-Sac Plain. Earthquakes are frequent in the plain (see pp. 338-350), and they may pro-

duce lines of weakness that permit the escape of artesian water. Earthquakes also cause sudden large flows of water due to the slumping and compression of water-bearing rocks. Such flows of water are generally temporary, but some may continue as permanent springs. Several reports indicate that flows of this kind in the plain have been produced by earthquakes.

SPRINGS IN FRACTURES IN IMPERVIOUS ROCKS.

Another type of spring is that due to fractures or fissures in relatively impervious rocks. To this type probably belong a number of small springs whose water circulates through joints, simple or complex, entering them at high altitudes and issuing at lower. Of this type also are springs that issue along fault zones that probably extend to considerable depth in the earth. Some of the more noted warm springs of the Republic are doubtless of this class. (See p. 565.)

UNUSUAL TYPES OF SPRINGS.

Many springs in the Republic that can be referred to the above types so far as the attendant rock structure is concerned, have distinctive features of other kinds, such as highly mineralized water, included gases (particularly hydrogen sulphide), or a temperature markedly above the general average of the atmosphere. The larger ones noted can be classified as salty springs (contaminated by sea water), sulphur springs, and warm springs.

Salty Springs Contaminated by Sea Water.

Salty springs appear to be rather common, particularly on the limestone coasts. Among the best examples of the type are two springs southwest of Miragoâne, where the coast is high and steep. The larger spring is on the shore about a kilometer from the town. The spring (Pl. XL, *B*) issues from large open solution channels in a low bluff of Eocene limestone very close to the sea. The water level in the large basin-like pool at the outlet rises and falls with the tides, which enter beneath the bridge to the north. The flow of the spring is probably at least 100 liters per second. The water is very salty, quite unfit for drinking. The smaller spring, which is nearer the town, is much like the larger one, but its flow is less and its water is more salty. Analyses of the water of these two springs, compared to sea water, are given in the table on page 554.

Graphic comparisons of these waters with sea water are given in Figure 33. The ratios of all the significant bases and radicles in the spring waters to the total solids and to each other is virtually the same as in sea water, so that the only notable difference is the degree of concentration. Of course a part of the calcium and most of the silica and bicarbonate in the spring waters are derived from normal meteoric ground

water, but nearly all the chloride, sulphate, carbonate, sodium and potassium, and magnesium is derived from sea water, probably in part by diffusion, in part by the infiltration of sea water into open crevices at high tide, and perhaps in part by displacement of fresh water by sea water, particularly at high tide, because of the greater specific gravity of the sea water. The sea water, probably affects only the water at and near the outlet of the springs.

Other springs of this type are not uncommon. The Source Salée between Léogane and Port-au-Prince, the springs at Grand-Gosier, and the Source Baie de Henne (p. 590) are examples.

Analyses of water of salty springs near Miragoâne and of sea water.

[Parts per million.]

	Larger salty spring.[a]	Smaller salty spring.[a]	Sea water.[b]
Total dissolved solids	10,476	20,928	35,000
Silica (SiO_2)	77	79	.....
Iron (Fe)	.25	.45	.....
Calcium (Ca)	178	183	419
Magnesium (Mg)	387	675	1,304
Sodium and potassium (Na+K)	3,224	6,752	[c]11,094
Carbonate radicle (CO_3)	34	48	72
Bicarbonate radicle (HCO_3)	272	220	.....
Sulphate radicle (SO_4)	763	1,551	2,693
Chloride radicle (Cl)	5,559	11,376	19,352
Nitrate radicle (NO_3)	Trace	Trace	.....
Date of collection	Apr. 10, 1921	Apr. 10, 1921	1873-1876

[a] C. S. Howard, analyst.

[b] From U. S. Geol. Survey Water-Supply Paper 258, p. 82, 1910, after Dittmar.

[c] Sodium (Na) 10,707, and potassium (K) 387 parts.

Sulphur Springs (Sources Puantes).

A number of springs in the Republic contain hydrogen sulphide (H_2S) in solution. Most of this gas escapes when the water reaches the surface and pressure on it is released. The unpleasant odor of the gas suggested the name sources puantes, which is frequently applied to these springs. The most famous are the Sources Puantes at the northwestern corner of the Cul-de-Sac Plain. (See Pl. XXXIX.) The odor of these springs is very strong and can be detected for some hundreds of meters. A view of the springs is given in Plate XL, *C*.

The Sources Puantes are on a very narrow extension of the Cul-de-Sac Plain, not more than 100 to 200 meters from the sea, at the base of low foothills that border the higher mountains north of the plain. The foothills consist of Miocene rocks, but near the springs they are surfaced with gravel and conglomeratic débris. The plain is alluvial. It stands virtually at sea level and becomes a mangrove swamp only about 50 meters from the outlet of the springs.

The original outlet of the springs has apparently been disturbed a little by the building of a railroad embankment and highway crossing. The present flows issue from two small basins at the lower side of the embankment. Some water also seems to seep out over a marshy area that is at least 100 meters in diameter. Bubbles of gas rise almost continuously both at the larger openings and at many places in the adjacent marsh. Presumably most of it is hydrogen sulphide (H_2S). The total flow of the two springs at the railroad embankment amounts, probably, to at least 30 liters per second. The water had a temperature of 32.7° C. on December 6, 1920, with the atmospheric temperature at 29° C. The mean annual temperature at Port-au-Prince is 27° C. and is probably nearly the same at the springs. The water is clear, but very salty and rather nauseating to the taste.

The water probably rises along a fault that borders the north side of the Cul-de-Sac Plain, as faulting doubtless had some share in the formation of the greatly depressed region of the plain and faults were discovered on the south side of it. (See p. 335.) If there is no fault at this locality the water may possibly escape because the alluvial sediments at the margin of the plain are coarser and more porous here than they are to the south and east. The water probably rises because of artesian pressure, such as accounts for other springs and for flowing wells in the lower part of the Cul-de-Sac Plain.

The high temperature of the water is believed to be due to the considerable depth from which it comes, for, as is well known, the temperature of the earth increases with depth. An average figure for the rate of this increase of temperature with depth near the surface of the earth probably is about 1° C. for each 35 meters of depth. A figure very commonly used by English and American writers is 1° F. for each 50 to 60 feet in depth, equivalent to 1° C. for each 27 to 33 meters.[1] Some recent and very careful measurements by C. E. Van Orstrand, in West Virginia, indicate that the rate is somewhat less, particularly in very deep wells. An average increment of 1° C. for each 43 meters in depth was obtained from measurements in 6 wells ranging in depth from 2,000 feet to 7,310 feet (610 to 2,228 meters).[2] The rate of increase varies considerably in different parts of the world and even in nearby localities, so that at best only an approximation is possible. The figure used here of 1° C. for each 35 meters of depth is believed to be conservative, and the water of the Sources Puantes would therefore need to circulate only about 5×35 meters or 175 meters, beneath the surface to attain a temperature of 5° above the mean atmospheric temperature. Allowance must be made for the loss of heat along its path to the surface, but probably not enough to increase the depth unreasonably. The depth given is no greater than that of some

[1] See Chamberlain and Salisbury, Textbook of geology, vol. 1, p. 569, 1905.

[2] See Darton, N. H., Geothermal data of the United States: U. S. Geol. Survey Bull. 701, pp. 90-95, 1920.

of the artesian wells on the plain. The temperature of the water in these wells is slightly higher than atmospheric temperature.

The salinity of the water appears from the analysis to be due to sea water, as is shown by a comparison of analyses in the table below and in the charts in Figure 33.

Analysis of water of Sources Puantes compared to sea water.

[Parts per million.]

	Water of Sources Puantes.[a]	Sea water.[b]
Total dissolved solids	12,684	35,000
Silica (SiO_2)	36	.....
Iron (Fe)	.08	.....
Calcium (Ca)	397	419
Magnesium (Mg)	299	1,304
Sodium and potassium (Na+K)	3,930	[c]11,094
Carbonate radicle (CO_3)	.0	72
Bicarbonate radicle (HCO_3)	610	.....
Sulphate radicle (SO_4)	872	2,693
Chloride radicle (Cl)	6,627	19,352
Nitrate radicle (NO_3)	Trace	.....
Hydrogen sulphide (H_2S)	136	.....
Date of collection	Dec. 6, 1920	1873-1876

[a] C. S. Howard, analyst.

[b] From U. S. Geol. Survey Water-Supply Paper 258, p. 82, 1910, after Dittmar.

[c] Sodium (Na) 10,707 and potassium (K) 387 parts.

The close resemblance to sea water is striking. The total solids, magnesium, sodium and potassium, sulphate, and chloride—the significant factors—all bear a ratio of about one-third to the concentration of sea water. Most of the calcium and the bicarbonate may be derived from normal meteoric ground water. The presence of sea water seems unquestionable; though the question how it comes to be present is not easily answered. It might enter by direct seepage into the upper strata near the outlet of the springs, by infiltration along a fissure or fault zone opening beneath the sea, or as connate water that was imprisoned in marine beds beneath the plain at the time of their deposition and that is now being gradually replaced by fresh meteoric ground water, which is seeping seaward under pressure. The first two assumptions are not regarded as very probable. Observations made elsewhere show that salt water seldom invades uniformly textured alluvial or sedimentary rocks that are exposed at the surface along beaches, especially when the escaping ground water has a considerable head forcing it seaward, as at the Sources Puantes.[1] This head of fresh water also probably would prevent the salt water from entering fissures in the sea bottom and would tend to form submarine fresh water springs instead. The assumption that this is connate sea

[1] Brown, John S., A study of coastal ground water: U. S. Geol. Survey Water-Supply Paper. (Awaiting publication.)

water, coming either from the young marine beds beneath the alluvium of the plain or from the buried Miocene beds, therefore seems reasonable, and accords also with the theory that the hydrogen sulphide is derived from sea water that ascends from considerable depths.

The hydrogen sulphide is probably produced from the sulphate that was originally in the sea water by chemical reactions due to the agency of organic matter in the rocks traversed by the rising water, particularly near the surface. The ground around the spring, especially the mangrove swamp nearby, is full of organic matter, which doubtless occurs also in considerable amount in lower beds, as the shore line probably has been near the same place for a long time. Clarke[1] says "The sulphates of a water, by accession of organic matter, can be partly or entirely reduced to sulphides, and carbonic acid, acting upon the latter, may expel sulphureted hydrogen and produce carbonates." This is apparently the type of change that has occurred here. The necessary carbonic acid is abundantly present in all the normal meteoric ground water of the Republic, such as must constitute the two-thirds of the water not derived from the sea. Additional support is lent to this theory by the fact that the sulphate in the spring water is slightly less than one-third that in normal sea water, but the chloride and sodium and potassium are slightly greater than one-third, indicating perhaps the reduction of a small amount of sulphate.

The Sources Puantes are regarded by many people as having therapeutic value. A basin for bathing has been sunk in the mud of the marshy area, flush with the surface of the ground. It is about 2 meters in length and somewhat less in depth and width and appears to be walled with either brick or stone. It has no roof, and does not appear to be much used. There are no houses near the springs.

Nearly all the warm springs of the Republic contain slight traces of hydrogen sulphide, particularly those at Los Pozos. (See p. 564.) Moreau de St.-Méry[2] describes what apparently is a notable sulphur spring at the foot of the mountains southwest of Port-de-Paix near the boundary between Bas Moustique and Haut Moustique. The hydrogen sulphide in some of these springs may be derived from other sources than those suggested for the Sources Puantes.

Warm Springs.

The Republic contains no boiling springs, but a few springs are distinctly warm and exhibit unusual features. Nearly all these springs are known by the generic name of Sources Chaudes, and local geographical names are added to distinguish them from one another.

[1] Clark, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 695, p. 204, 4th edition, 1920.

[2] Op. cit., vol. 1, p. 715.

SOURCES CHAUDES OR EAUX BOYNES.

The Sources Chaudes on the southern side of the Northwest Peninsula, also known as Eaux Boynes, are the most celebrated warm springs in the Republic. They are about 12 kilometers west of Terre-Neuve and 30 kilometers northwest of Gonaïves. The springs have long enjoyed the reputation of having great curative properties, particularly for skin diseases and rheumatism, and they have been frequented a great deal by invalids. Moreau de St. Méry[1] gives a lengthy description of the springs and of their utilization by the colonists. They were discovered and their curative properties were first tested by a negro named Capois in 1725. Their fame spread until they came to be frequented by invalids of many classes, and they are credited with some remarkable cures. In 1772 the owner of the springs, M. de Rameur, made a gift of them to the Crown in order that they might be used more fully for the public good. Under governmental direction a public bath-house with sixteen masonry baths and a sanitarium, open to the public at reasonable rates, were erected. A military hospital, with separate baths for soldiers, was also maintained. A passenger boat made regular bi-monthly trips between Cap-Haïtien and the landing at Port-à-Piment. Beautiful avenues of trees were planted and the place must have had a prosperous appearance, strongly in contrast with its present dilapidated condition.

Only the ruins of 8 of the masonry baths now remain. There is a small agricultural settlement at the springs, but no attempt is made to exploit them either by public or private enterprise, although many invalids still frequent the place on their own initiative. The water from the springs still makes the place a green and pleasant oasis in the surrounding semiarid region and permits the irrigation of garden spots in a small area. The ownership of the springs is still vested in the Government.

The Sources Chaudes are about 8 kilometers from the coast, at the interior edge of the Arbre Plain. Behind them, to the north and east, is a narrow belt of low foothills, which borders the steep southern escarpment of the easternmost range of the Montagnes du Nord-ouest. This range rises more than 1,000 meters above sea level. The altitude of the springs is less than 100 meters above sea level.[2] The relative position of the springs and the surrounding surface features are shown in Figure 34. Of the six distinct springs now visible, five are ranged along a remarkably straight line trending about N. 55° W. across a low divide between two shallow ravines. The distance between the springs at the extremities of the line is about 235 meters. The sixth spring is offset considerably to the south of the easternmost spring. The line of springs plainly occupies a position at the break in the slope from the foothills to the plain. Geologically it also appears to occupy a well-defined contact. Only alluvium and

[1] Idem, vol. 2, pp. 62-75.
[2] Given as 70 meters by Tippenhauer.

residual soil are visible near the springs, but the plain is underlain by Miocene rocks, which are exposed not far to the south, and the surface features suggest that the whole plain is formed on the soft marly beds of

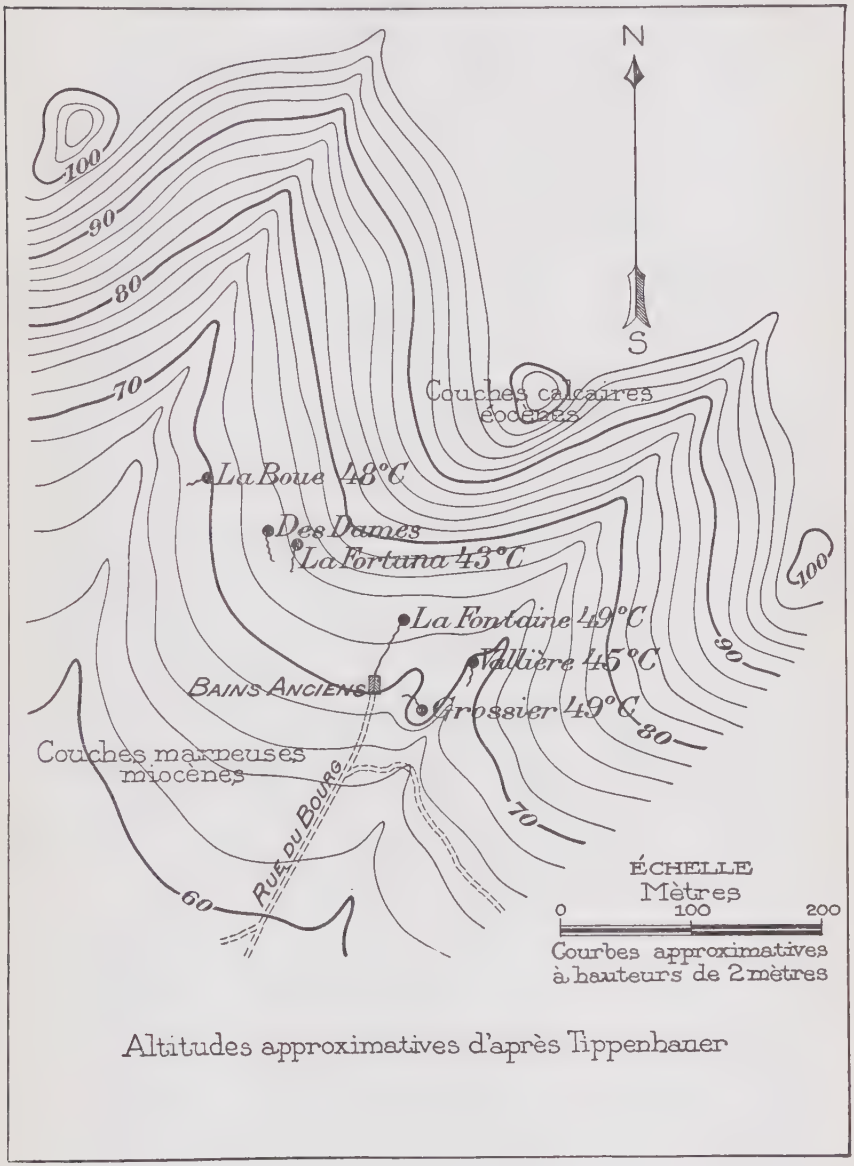


FIGURE 34.—Sketch map of the Sources Chaudes or Eaux Boynes.

Miocene age. On the other hand, the foothills are generally composed of limestone, which is exposed on the hill about 200 meters northeast of the springs. The limestone is hard, yellowish-white, and unfossiliferous,

and generally resembles a facies of the upper Eocene limestone. The exposure is poor, however, and the bedding is indeterminable.

Only six springs can now be found, although it is said there were once seven. Some of the springs, particularly Des Dames and La Fortuna, appear to have been developed by excavating at seeps, and the lost spring is probably one of this type, which has become covered with débris and ceased to flow.

Source Grossier is 50 or 60 meters south of the east end of the main line of springs. It is on a distinct knoll that rises from a little ridge on the bank of a ravine about 3 meters in depth. Black soil full of plant humus forms the mound, which is covered by a thick tangle of trees, chiefly bayahonde. The water does not flow from the crest of the knoll but mainly from an outlet on its western side, away from the ravine. A little water also issues on the side nearest the ravine. The temperature in the little pool at the main outlet is 49° C. The flow probably does not exceed 10 liters a minute. No use is made of the water.

Source Vallière is in the bed of a shallow ravine and issues from a small basin in soft soil. It yields perhaps 20 liters a minute, and the water has a temperature of 45° C. It is not used much, if any.

Source la Fontaine rises from a bowl-shaped basin about half a meter in diameter in soft black soil. It is probably the largest of the springs, flowing perhaps 40 or 50 liters a minute. The temperature of the water in the outlet is 49° C. Bubbles of gas rise very slowly, at intervals of several seconds, with the water. There is little if any odor, however, and only a trace of H_2S could be found, so that it is apparently some other gas. The water flows through a canal for 50 or 60 meters to the ruins of eight masonry baths. It also feeds a fountain at the baths and a trough for watering stock. Virtually all the water for domestic use and drinking in the village is carried from this fountain. The water is clear, and although it has a slightly peculiar taste is neither unpleasant nor harmful, even when taken warm.

Source la Fortuna and Source des Dames are covered and issue through short aqueducts. They are used for laundry work and probably to a small extent for irrigation. No temperature reading could be obtained near the outlet of Des Dames, and that given for La Fortuna (43° C), was taken at a seep from a break in one side of the cover and is perhaps too low. The flow of each spring is probably less than that of La Fontaine.

Source la Boue evidently receives its name from a large pool of dirty water, several meters in diameter, into which it flows. Like some of the other springs, it issues from a very small basin in black earth. It yields only 15 to 20 liters a minute and has a temperature of 48° C. Bubbles of gas rise at intervals, as from La Fontaine. The spring is not used.

Of the seven springs listed by Moreau de St. Méry, only two, Vallière and Des Dames, bear the same names today, and indeed it is not certain

that these names still apply to the springs that were originally so designated.

The remarkable alignment of all but one of the springs and their position along a break in the surface features and a geologic contact suggest very strongly that they issue from a fault zone. The alignment, moreover, is parallel to the trend of the regional structural features, which extend northwestward. No positive evidence of faulting was obtained, however.

The most reasonable assumptions regarding the source of the water and the manner in which it becomes heated appear to be: (1) that it is meteoric water heated (a) by descending to great depth, or (b) by coming in contact with buried masses of hot igneous rock; (2) that it is juvenile or magmatic water escaping from cooling masses of igneous magma. It is an open question whether or not it is possible to distinguish meteoric from magmatic waters. Clarke,[1] following Gautier,[2] says:

> Vadose waters, or waters of infiltration, are characterized by fluctuations in composition, concentration, and rate of flow, depending upon local and variable conditions such as abundant rain or drought. They also contain as a rule carbonates of lime or magnesia, chlorides, and sulphates. Virgin or juvenile waters, on the contrary, are fairly constant in all essential particulars and carry sodium bicarbonate, alkali silicates, heavy metals, etc., as chief constituents, with chlorides or sulphates only as accessories, and practically no carbonates of the alkaline earths. The vadose waters, moreover, issue from faults having no relation to the metallic veins of the surrounding territory—a lack of relation which is conspicuous as regards juvenile springs.

The terms vadose and juvenile, used here, are equivalent to meteoric and magmatic, respectively, as used by the writer. The distinction then, between meteoric and magmatic water must be sought in chemical analysis, which may or may not be conclusive. The following is an analysis of water from La Fontaine.[3] This analysis is shown in Figure 32, page 548.

Analysis of water from the Sources Chaudes, or Eaux Boynes, collected at Source La Fontaine, August, 1921.

[Parts per million. C. S. Howard, analyst.]

Total dissolved solids	403
Silica (SiO_2)	35
Iron (Fe)	.3
Calcium (Ca)	51
Magnesium (Mg)	21
Sodium and potassium (Na+K)	56
Carbonate radicle (CO_3)	.0
Bicarbonate radicle (HCO_3)	277
Sulphate radicle (SO_4)	68
Chloride radicle (Cl)	36
Nitrate radicle (NO_3)	Trace.
Hydrogen sulphide (H_2S)	Trace.

[1] Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 695, p. 208, 1920.
[2] Gautier, Armande, Compt. Rend., vol. 150, p. 436, 1910.
[3] Bottle containing sample collected by the writer was broken in shipment and sample analyzed was collected by Père J. J. Joliveau of Terre-Neuve, in August, 1921.

Most of the analytical criteria listed by Clarke favor the conclusion that this water is meteoric. It contains predominantly carbonate of lime and magnesia in bicarbonate form, characteristic of the meteoric waters of the Republic, although the quantities of alkali chloride and sulphate are also relatively large. Silica is low, very little above the average for normal meteoric waters. Whether the springs exhibit seasonal fluctuations in volume or concentration is not known, although Moreau de St. Méry asserts that the current opinion was that they did not. Fluctuations in water that admittedly must circulate deep within the earth probably would be small and not synchronous with the observed seasonal influences.

The water may be heated partly by a buried mass of hot intrusive igneous rock. Small bodies of igneous rock, probably not later than Miocene, are intruded into the upper Eocene rocks of Terre-Neuve, not far away. If the water is heated solely by its descent into the interior it must circulate rather deeply. The warmest springs have a temperature of 49° C., about 22° higher than the mean annual temperature, which probably is nearly the same as that of Gonaïves, 27.1° C. As the assumed increment of heat is 1° C. for each 35 meters of depth[1] this water must come from a depth of at least 880 meters, and an allowance of greater depth must be made to compensate for its cooling on the way to the surface. It is doubtful whether masses of hot intrusive rocks lie near the surface of the earth, but it is not improbable that the increment of temperature with depth at this locality may exceed the normal and thus the required depth of circulation may be considerably lessened. On the other hand if hot igneous masses really lie near enough to the surface to heat the water it might quite as reasonably be supposed to be of magmatic origin. The presence of escaping gas, probably CO_2, would seem to favor the view that the water may be of this origin.

SOURCES CHAUDES DE LOS POZOS.[2]

The Sources Chaudes de Los Pozos are on the estate of Charles Zamor, in the Section Los Pozos, about 6 kilometers southeast of Cerca-la-Source. The springs are not much used for any purpose, although they are commonly supposed to have therapeutic value, especially in the treatment of skin diseases. At two of the five springs there are crude shelters for bathers, but there is no settlement at the springs.

The springs are at the southern border of the valley of Rivière l'Océan, and at the foot of a rounded escarpment in upper Oligocene limestone. Farther northwest, near Cerca-la-Source, this escarpment becomes high and precipitous. The valley is underlain by argillite of Cretaceous(?) age. Of the five springs in the group, four are arranged along a straight line trending about N. 70° W., at the northeast side of the trail from

[1] See p. 555.

[2] The descriptions and sketch map are based entirely upon information supplied by W. F. Woodring.

Cerca-la-Source to Los Pozos. One is southwest of the trail. The relative position of the springs and the chief surface features of the locality are shown in Figure 35.

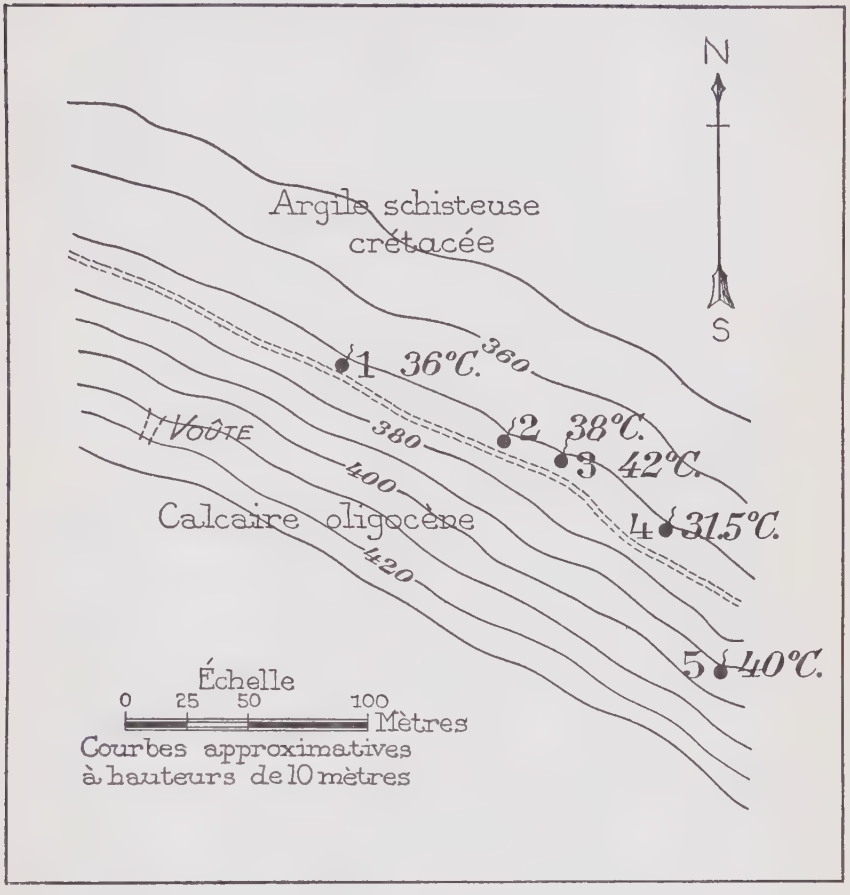


FIGURE 35.—Sketch map of the Sources Chaudes de Los Pozos.

1. Water seeps out along the trail and is conducted about 5 meters down the slope to a wooden tub, hollowed out from a log. There is a crude shelter over the tub. The temperature of the water was 36° C.

2. This is a small seep and is not cleaned out. Temperature 38° C.

3. This is the largest spring of the group; all the springs have a very small flow. It has also the highest temperature (42° C). The water issues from an opening between two large limestone boulders that have fallen from the slope above. There is a strong odor of hydrogen sulphide (H_2S), and sulphur is precipitated on the surface of the water. Bright green algae also grow in abundance. A crude shelter has been built for bathers.

4. A small spring, not cleaned out. Temperature 31.5° C.

5. This spring has been developed by digging a trench in the slope of the ridge. The opening is walled with rough limestone blocks. Temperature 40° C.

There is probably a fault at the base of the limestone escarpment that borders the long valley of Rivière l'Océan, and certainly there seems to be good reason to assume a fault at the springs, which are aligned parallel

to the geologic contact and to the strike of the surrounding rocks. Presumably the water issues along the fault zone.

There seems to be less reason here than at Eaux Boynes to invoke the aid of heated igneous rock to account for the temperature of the water. The warmest spring has a temperature of 42° C., and the mean annual temperature of the air is probably about 25° C., a difference of 17° C. If the average rate of increase of temperature is 1° C. for each 35 meters the water should rise from a depth of about 600 meters, to which a little may be added to allow for some cooling on the way. This may not be an unreasonable depth for water to penetrate along fault lines, especially in regions that stand several hundred meters above sea level. The following is an analysis of the water from spring 3, Figure 35.

No. 3, Figure 35.

[Parts per million. C. S. Howard, analyst.]

Total dissolved solids	1,214
Silica (SiO_2)	15
Iron (Fe)	.13
Calcium (Ca)	118
Magnesium (Mg)	33
Sodium and potassium (Na+K)	223
Carbonate radicle (CO_3)	.0
Bicarbonate radicle (HCO_3)	260
Sulphate radicle (SO_4)	62
Chloride radicle (Cl)	464
Nitrate radicle (NO_3)	Trace.
Hydrogen sulphide (H_2S)	Odor.
Date of collection	Mar. 14, 1921

A graphic representation of this analysis is given in Figures 32 and 33, pages 548-549.

The outstanding feature of the water is the higher proportion of alkali chloride compared to normal spring waters and the lower proportion of calcium bicarbonate. There is little reason to attribute the salinity of this spring to sea water, or even to connate water, and the relatively high chloride is probably more explainable by supposing that the water circulated through rocks containing an unusually large amount of chloride, perhaps some of the beds in the argillites, or by supposing that it is of magmatic origin. The hydrogen sulphide may easily be produced by chemical reactions similar to those suggested on page 557.

WARM SPRINGS OF THE SOUTHERN PENINSULA.

There are a number of warm springs in the interior of the Montagnes de la Hotte, in the western part of the Southern Peninsula. According

to statements made by Moreau de St. Méry[1] and other writers there are warm springs at four places, three on the Bras-à-Gauche, the eastern fork of the Grande Rivière de Jérémie, and one along the Bras-à-Droit, the western fork of the same stream. Two of these places are near the headwaters of the Bras-à-Gauche, one on a tributary ravine about 600 meters west of that stream, and one in the bed of the Bras-à-Gauche about 600 meters downstream from this ravine. These springs are variously known as the Sources Chaudes or Eaux Thermals de La Cahouane or de Tiburon. According to Moreau de St. Méry their temperatures were 34° C. and 37.5° C. About two leagues downstream from these springs are the Sources Chaudes de Dame-Marie or de Jérémie, described below. Considerably farther west on the headwaters of the Bras-à-Droit, near the bed of its deep, narrow valley, are the Sources Chaudes des Irois, or de l'Anse d'Hainault. All the springs are supposed to have medicinal virtues and are considerably frequented by persons who live near by. The region is so rough and inaccessible, however, that it is very thinly inhabited and is seldom visited by strangers.

Sources Chaudes de Dame-Marie or de Jérémie.

The springs called Sources Chaudes de Dame-Marie or de Jérémie are on the Bras-à-Gauche (east fork) of the Grande Rivière de Jérémie, about 15 kilometers by trail above its junction with the Bras-à-Droit. The trail follows the river at places but not all the way. It is very rough and rocky and difficult for horseback travel. At the springs there are about half a dozen little thatch shelters occupied by the transient visitors, but there are no permanent habitations.

The valley of the Bras-à-Gauche is deep and narrow, and is incised directly across the mountain ranges. In the vicinity of the springs the valley is narrow and V-shaped, but not so deep as it is farther north, the mountains being probably not more than 500 or 600 meters higher than the river. The aneroid barometer read 190 meters above sea level in the valley, near the springs, but the atmospheric conditions were very unstable and the instrument had not been set for two days, so that this reading is probably not very accurate.

There are two springs about 50 meters apart on the southwest bank of the stream, which flows northwestward. The most southerly spring is about 4 meters above the river bed and the other only about 1.5 meters above it. The slopes above and behind the springs are very steep. The outlet of the lower spring is best exposed. It issues from a small fracture in basalt, an inch or two in width. The other also doubtless issues from a fracture but its outlet is obscured by débris. The water bubbles up from each spring with considerable force, but no gas bubbles were seen, and there is only a faint suggestion of an odor. The temperature of the water is probably 35° or 40° C., but no thermometer was available. One can

[1] Op. cit., vol. 2, pp. 759-760.

hold the hand in either spring indefinitely without discomfort. There are no bathing facilities except a sort of earthen-walled and rock-floored basin that has been scooped out at the lower spring. A quaggy area of mud below the other spring is a favorite place for mud baths. The taste of the water is not unpleasant.

Aside from other considerations the temperature of this water is not high enough to necessitate the assumption that it is either of magmatic origin or that it has been heated by buried intrusives. All its heat might easily result from circulation along deep fractures, joints, or fault zones. The analysis shows, however, that the water is decidedly different from that of the other warm springs and in fact from that of all the other waters of the Republic for which analyses are available.

Analysis of water from the Sources Chaudes de Dame-Marie or de Jérémie.

[Parts per million. C. S. Howard, analyst.]

Total dissolved solids	515
Silica (SiO_2)	68
Iron (Fe)	.07
Calcium (Ca)	26
Magnesium (Mg)	1.4
Sodium and potassium (Na+K)	135
Carbonate radicle (CO_3)	.0
Bicarbonate radicle (HCO_3)	93
Sulphate radicle (SO_4)	117
Chloride radicle (Cl)	121
Nitrate radicle (NO_3)	.42
Date of collection	Nov. 16, 1920

This analysis is represented graphically in Figure 32, page 548. In view of its probable circulation at considerable depth the water is not highly mineralized. The alkali sulphate and chloride are relatively very high, particularly the sulphate. Calcium and magnesium bicarbonates are very low compared to those found in the normal waters of the Republic. Silica is unusually high. The last two features might be interpreted as favoring a magmatic origin for the water. The differences between this water and other mineral waters of the Republic may arise chiefly from its circulation entirely through volcanic rocks, but the occurrence of many warm springs in this area, which is an area of volcanic rocks, might strongly suggest that this water is of magmatic origin.

PUBLIC WATER SUPPLIES.

PORT-AU-PRINCE.

Purpose of Investigation.

The water supply of Port-au-Prince has been for many years unsatisfactory and inadequate for the needs of its growing population. Owing to long-continued dry weather the shortage of water in 1919 and 1920

was distressing. The writer therefore spent about two weeks in October, 1920, in a study of the geology of the vicinity of Port-au-Prince with special reference to its bearing on the present and possible future sources of water supply. The results of this study were submitted to the Engineer in Chief in the same month in the form of a preliminary report. The substance of this preliminary report is given here, with such modifications as have been suggested by later developments and with the omission of certain material that is given elsewhere in this report.

Sources and Distributing System.

The water for Port-au-Prince is conveyed to it from springs in the foothills of Morne Hôpital, south of the city. The location of these and other springs and their relation to the principal geologic features are shown in Figure 36.

The springs used are Plaisance and Cerisier, Turgeau, Le Clerc, Chaudeau, and Diquini. Sources Chaudeau and Diquini have been added to the supply in recent years, Diquini having been connected only in 1921. The others were appropriated by the colonists soon after Port-au-Prince was established and have served continuously since.

In utilizing a spring an excavation has been made at its visible outlet to remove all soil and loose material so far as possible and a masonry housing has been placed over the excavation. Open stone aqueducts were used by the colonists to carry the water to the city, but these aqueducts have probably all been replaced or repaired, and the newer lines to Chaudeau and Le Clerc are constructed in great part of large cast iron pipe. All the masonry conduits now in use are covered, although holes have been broken in the covers at many places and some of them are poorly repaired. None of the aqueducts is strong enough or tight enough to carry water under pressure, and large manholes (regords) are therefore introduced in the line at intervals of about 100 or 200 meters. The manhole is a large square chamber about 2 meters deep with an iron cover. It receives water from the section above and discharges it by overflow into the section below, thereby dissipating any pressure accumulated in the closed aqueduct above. As a matter of fact, however, the aqueducts seldom run full except at points where inverted siphons are used to carry the water across deep ravines.

In the higher, more fashionable residence sections of the city the water is distributed through private pipe lines of very small diameter, which are tapped into the manholes. Ten or twenty such lines may be inserted in one manhole and some of them are as much as a hundred meters long. The pressure depends of course upon the height of the manhole above the consumer's tap.

In the downtown business section the water is distributed through cast iron mains of different sizes, most of them 4 to 6 inches in diameter.

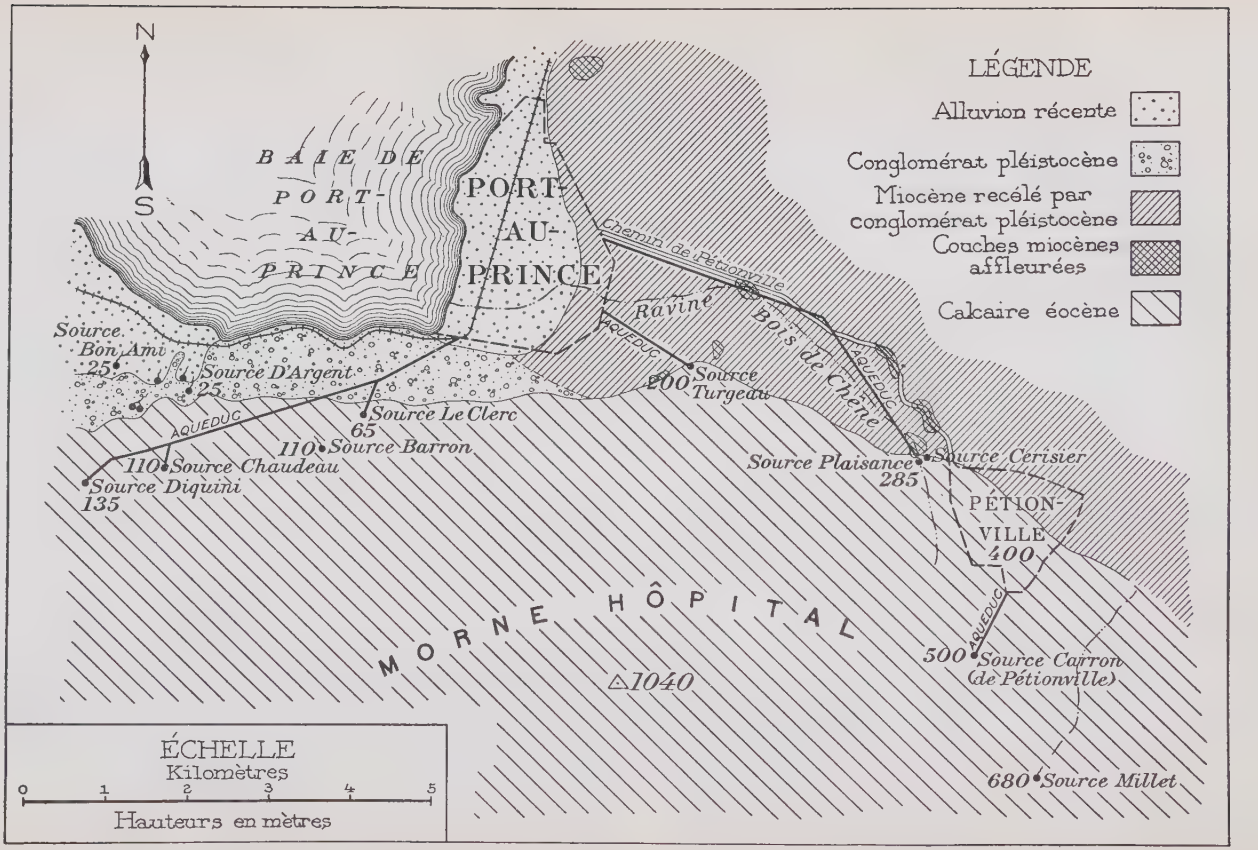


FIGURE 36.—Sketch map showing the water supply of Port-au-Prince and its relation to the geology.

These mains, like the aqueducts, are in poor repair and are unable to bear much pressure, so that no attempt is made to keep the system tightly closed. Most of the people obtain water from public fountains, some of which run continuously if there is any water in the pipes, and excess water is allowed to waste.

Calcareous deposits in the water mains are a source of much annoyance and expense. The small private pipe lines become stopped up in a few years, and even many of the large city mains have been almost entirely closed by such deposits.

The water service is not metered in any part of the city. Owing to the defects in the water supply, fire protection in the city is very inadequate. There is no sewer system whatever.

Although the present water supply system is very imperfect and inadequate, owing to its inherent and inherited defects, the present Hydraulic Service is doing much to improve it with the scant facilities and funds available.

Yield of Springs.

No accurate data are available to show the quantity of water yielded by the springs that supply Port-au-Prince. Two estimates, based apparently on single measurements, are as follows:

Yield of springs supplying Port-au-Prince.

Source.	Liters per second.	
Plaisance and Cerisier	[a]30	[b]66
Turgeau	[a]17	[b]37
Le Clerc	[a]25	[b]25
Chaudeau	[a]30	[b]44
Diquini	[c]80	[c]80
Total	182	252

[a] From report of Thomas Price, engineer, to M. John Laroche, Secy. d'État, Dept. des Travaux Publics, July 29, 1914.

[b] From Report of R. A. Conard, civil engineer, U. S. N., to Engineer in Chief, May 6, 1918.

[c] Oral communication by Lieutenant Diehl, Dept. des Travaux Publics, 1920.

If the springs supply an average of 200 liters a second the daily total is from 17 to 20 million liters. For an estimated population of 125,000 this is about 150 liters per capita a day, a very fair quantity compared to many large cities in all countries except the United States, where the average is considerably higher. A great deal of the water is practically wasted through leaky pipes, running fountains, careless use by patrons favorably situated at high altitudes, and especially because there is no storage space to conserve the surplus night flow.

Another serious fault is that the flow of the springs fluctuates greatly from season to season as all the springs depend on rainfall for their

maintenance. The actual amount of such seasonal fluctuations is not certainly known, but it can be judged from the records at Source Despuzeaux (p. 517), which indicate that the maximum flow is nearly three times as great as the minimum. A series of dry years, such as is not uncommon, causes great water shortage. This defect is unfortunately inherent in nearly any spring-fed system in regions where the rainfall is unevenly distributed, and its consequences are aggravated by habits of wastefulness acquired during times of super-abundance of water, which persist during periods of shortage.

Geologic Features and Their Relation to Water-Supply.

As there was no suitable base map and as little time was available it was impossible to map the geology near Port-au-Prince in detail. Most of the work had to be done on foot, for the country is very rugged and most of the uncultivated mountain slopes are covered with thick brush. There are four distinct series of sedimentary rocks in the region. Their general distribution is shown in Figure 36. The Miocene beds are probably exposed at many more localities than are shown on the map.

Limestone of late Eocene age (see p. 130) forms the mass of Morne Hôpital and is the oldest rock in the region. It is hard and white. Some parts of it are massive; other parts distinctly show bedding planes. It is strongly folded, so that the beds dip steeply, generally northward, on the north side of Morne Hôpital. Some faults are known and joints are very common. Many of the joints and bedding planes have been enlarged by solution and form channels for the circulation of ground water. The presence of sink holes on the broader part of the crest of Morne Hôpital indicates that solution has been very active and has formed large underground cavities. Because of its porosity the limestone absorbs water freely and most of the drainage is subterranean, surface streams flowing only during heavy rains. The water absorbed by this limestone gives rise to all the springs near Port-au-Prince. The other rocks are important chiefly for their influence in determining the location of springs, most of which are in ravines among the foothills at the base of Morne Hôpital.

In the rolling hills east of Port-au-Prince outcrops of soft Miocene beds (see pp. 219-221) are found in road cuts and along ravines. These beds underlie this region continuously but are concealed at most places by younger rocks. The Miocene series here comprise beds of coarse conglomerate, silty sandstone, limestone, and clayey marl. These beds, like the beds of Eocene limestone, are sharply folded, the axes of the folds trending east-west or northwest-southeast. The beds of marl and silty sandstone are relatively impervious, especially the marl. Consequently, where the Miocene beds abut against the base of Morne Hôpital they form a barrier or dam to the ground water that is stored in the upper Eocene limestone and that is seeking an outlet at the base of the mountains. Sources

Plaisance, Cerisier, and Turgeau are apparently due to the escape of water that overflows this impervious barrier.

South and west of Port-au-Prince, at the base of Morne Hôpital, there is a belt of foothills of gentler slope than the main mountain mass. These foothills are composed of roughly stratified beds of coarse conglomerate consisting chiefly of limestone pebbles, and are probably of Pleistocene age. East of Port-au-Prince this conglomerate still covers the foothills but is nearly everywhere underlain by Miocene beds, although at some places it extends above them on the mountain side. The conglomerate is not folded, but it is considerably dissected. It is a porous rock and probably here and there absorbs a good deal of water from the upper Eocene limestone.

In the lower part of Port-au-Prince and at other places near the shore there is a belt of Recent alluvium, consisting of horizontal beds of gravel, sand, and clay. These sediments are not consolidated and are but little dissected. They underlie the narrow coastal plains. The alluvium is less pervious than the Pleistocene conglomerate, and ground water seeping seaward into the conglomerate at some places is forced to rise above the contact of the alluvium in springs, as in the group of springs including Source Bon Ami and Source d'Argent.

Some springs, like Le Clerc, Chaudeau, and Diquini, do not appear to be related to geologic contacts but occur at places where deep ravines in the foothills tap underground streams in the upper Eocene limestone.

Notes on Individual Springs.

Source Diquini issues in a deep, narrow ravine in upper Eocene limestone at a locality where the gradient increases rapidly upstream. Water originally rose through a few meters of alluvium in the bed of the ravine. This alluvium has been cleared away to solid rock, from which the water appears to come, and a concrete housing several meters long and wide has been constructed over the outlet. The spring appears to be effectively utilized.

Source Chaudeau, like Diquini, is in a deep ravine and probably issues from solution channels in the upper Eocene limestone, which crops out on both sides of the ravine. One small isolated vent west of the main source issues from bedding planes of the limestone. Most of the water, however, is contained in alluvial gravels, a few meters in depth, in the bed of the ravine. In developing the spring a concrete floor was laid over all this gravel bed for about 100 meters. This floor was intended to protect the water from pollution by floods or by careless local use. The water is collected in a deep pit that penetrates the gravels at the lower end of this concrete cover. The pit is covered by a concrete housing. The flow is probably developed about as advantageously as possible, unless perhaps the pit fails to reach bedrock and some water is lost by seepage. A little

water could be appropriated from the small outlet at the side, but it would not increase the yield a great deal.

Source Barron was not visited. The Hydraulic Service is said to have considered connecting it with Source Le Clerc, but decided that its small yield would not justify the expense.

Source Le Clerc is at the head of an especially narrow and steep-sided ravine. Limestone is exposed in a small bluff high above the spring, but the bottom and sides of the ravine are deeply covered by alluvial or residual soil, from which the water seeps out. The spring has been developed by a shallow excavation in this alluvium and has the usual concrete housing. Considerable water may be lost at this spring by seepage through the alluvium, and a good increase in flow probably could be obtained by sinking the excavation deeper, to bedrock if possible. This work however, would necessitate either lowering the aqueduct or building a water-tight subsurface dam, set on bedrock across the ravine.

Source Turgeau is in a remarkable natural amphitheater, about 100 meters in diameter, walled on three sides by steep slopes of upper Eocene limestone. On the other side it opens into a shallow ravine. The spring appears to be on the contact betwen the limestone and the Miocene beds, but the Miocene beds are obscured by a thin cover of Pleistocene conglomerate. Outcrops of Miocene rock are found both east and west of the springs. The water probably comes through solution channels in the limestone and rises over the dam formed by impervious Miocene beds. The outlet is obscured by soil and débris, however, and the water seeps out over a large area in the bottom of the basin-like depression. The spring has been developed by digging a series of ramifying trenches, 1 or 2 meters deep, in the soil. Water rises with some force in these trenches and collects to form a large stream. As the water appears to rise under some pressure through the confining soil the writer suggested that a larger and freer flow might be obtained by sinking some wells to considerable depth, to bedrock if possible, in the area where the trenches were constructed. This was tried but was found to be very difficult because of the water itself and because of the large boulders encountered. A substitute plan was then tried. It consisted of digging a long trench across the ravine below the springs, and placing a subsurface dam there to impound any seepage that might have escaped through the conglomerate and soil. The results of this experiment are not yet known.

Source Plaisance is in the bed of the Ravine Bois de Chêne, which is dry except during or immediately after rains. It is a considerable distance from the mountain front, although outcrops of upper Eocene limestone were seen not far away in the bed of the ravine. The water, however, appears to be mainly seepage water in alluvial gravels or in Pleistocene conglomerate in the stream bed. This seepage water is forced to rise to the surface by a dam of impervious Miocene beds that crop out in the ravine. At a point just below the spring these beds strike N. 75° W. and

dip 43° SW. They form a very effectual barrier to underground seepage. The excavation made in utilizing Source Plaisance is very shallow and extends only partly across the ravine bed. It would be better if it could be made a little deeper and wider, but the natural dam appears to force all the water to the surface and probably none is lost except the small quantity that is visible for some distance below the spring and that is left for the use of people who live nearby.

Source Cerisier is in a tributary ravine only a short distance from Source Plaisance and owes its origin to the same geologic feature. Its flow, however, is very small, and it becomes virtually dry in the dry season. There is little hope of developing more water from it.

Source Carron supplies the town of Pétionville. No especial attention was paid to it. At the point where it is utilized it consists of underflow in an enormous boulder fill in the bed of a ravine. The width of the boulder fill is 50 meters or more, and its depth is probably 10 or 15 meters. The boulders at the surface are from 15 centimeters to half a meter in diameter. The spring has been utilized by digging a deep pit in the boulder fill and housing it with concrete.

Source Millet, which appears to have other names, is a large spring 2 or 3 kilometers south of Pétionville, in the second large ravine east of that town. It is the largest unappropriated source of water available to supplement the Port-au-Prince supply. The spring is very near the trail to Furcy, which traverses the ridge just west of it. It is used only to a small extent by inhabitants near by.

The spring is in a large bouldery stream channel much like that described at Source Carron. Most of the water is contained in the boulder filling; only small flows—a few liters a minute—break out here and there at the surface at places where the boulders have been scooped out either naturally during floods or intentionally by people seeking water. The water is held up near the surface by beds of dense upper Eocene limestone, which are tilted vertically across the ravine. The most favorable place to develop the water is near the present area of largest flow, where the ravine is reasonably narrow and has walls of solid rock. If possible, all the loose material should be excavated in order to collect all the flow in the lowest part of the bedrock floor beneath the boulders. It is not easy to estimate the quantity of water available, but apparently there is a large flow beneath the surface. It would be difficult to construct an aqueduct, especially for the first kilometer, where the ravine is bouldery and steep-sided. The altitude of the spring, however, would permit diversion of the water into the Plaisance-Cerisier aqueduct at any desired locality.

Source Bon Ami, Source d'Argent, and near-by springs.—There is a group of small springs near Bizoton, the best known of which are Sources Bon Ami and d'Argent. They are at the rear of the narrow alluvial plain and are apparently supplied by ground water in the Pleistocene conglomerate, which is forced to rise over the impervious alluvium to reach the

sea. They are at altitudes probably between 25 and 40 meters above sea level, and their water could not be carried by gravity to any but the lower parts of Port-au-Prince. They might perhaps be used to good advantage in this way, for the water from all could be brought together easily and the terrane is favorable for the construction of a conduit. A large part of the water, however, is now used in irrigating land near the springs.

Other springs.—The inhabitants of the region know all the large springs but persons unacquainted with the country have difficulty in discovering some of them. Some small springs were doubtless not found by the writer, but probably none that are conveniently situated.

Well Water.

Because of the high cost of machinery and fuel it is not considered feasible to pump water for Port-au-Prince from wells, but flowing artesian water, if obtainable at altitudes that would permit its distribution by gravity, would be advantageous. There are few wells in the region and none of any considerable depth, so that any opinions as to the occurrence of ground water must be based mainly on the lithology and structure of the rocks.

The water table at most places in the upper Eocene limestone of Morne Hôpital must be far beneath the surface and wells sunk there would have to be very deep. There is no impervious cover to confine the ground water under pressure and flowing water is not to be expected.

The coarser and more porous beds of Miocene age probably contain water that may be at some places under artesian pressure due to confining beds of marl or silty sandstone, but the Miocene beds are complexly folded and somewhat faulted, so that any such favorable localities could be predetermined only from a very thorough knowledge of their structure, which can not be observed at the surface because the beds are at most places covered by younger rocks. Any attempt to reach artesian water in these beds would be entirely unwarranted. The only well drilled in the Miocene beds (No. 10, p. 525) penetrated no water-bearing beds and was dry. The location of this well, however, is manifestly unfavorable.

The Pleistocene conglomerate is very porous and should contain water at or a little above sea level in localities where it extends downward to that depth. At many places the formation is only a thin cap overlying Eocene or Miocene rocks and at such places it is probably dry. There is little if any possibility of obtaining flowing water from this conglomerate.

The alluvium should yield some water either from shallow or deep wells, but deep wells sunk near the sea would probably be salty, and shallow wells would almost certainly be badly contaminated by sewage in this thickly inhabited region, so that their water would not be fit for domestic use.

There are flowing wells on the Cul-de-Sac Plain, but, as stated on pages 526-527, it appears that flows are not likely to be obtained nearer to

Port-au-Prince than the latitude of Croix-des-Missions and that the head of all such flowing wells in the plain will be insufficient to supply water by gravity to any but the lower parts of Port-au-Prince.

Quality of Water and Treatment for Hardness.

The water used in Port-au-Prince has an agreeable taste and is generally considered good for domestic use. It is not polluted at the springs that furnish the supply, but it is or may be polluted at unprotected breaks in conduits and at poorly covered manholes or through carelessness of workmen making repairs. Chemical analyses of water from Plaisance and Turgeau springs were made by the United States Geological Survey in 1919. (See p. 543.) Presumably these analyses represent fairly well the mineral content of the entire supply, as all the springs are fed mainly by water that has traversed the upper Eocene limestone. The chief feature of the water is hardness in the form of calcium bicarbonate, which makes up more than three-fourths of all the dissolved solids.

Calcium carbonate itself is only slightly soluble in water, but when water containing it takes up carbon dioxide from the atmosphere or the soil the combination is likely to form calcium bicarbonate [$Ca(HCO_3)_2$], which is highly soluble. This reaction produces the considerable quantity of calcium bicarbonate found in most of the waters of the Republic. Calcium bicarbonate is an unstable compound, which readily breaks up on a change of conditions, such as an increase of temperature, which causes the water to lose its carbon dioxide and thereby its power to hold in solution the carbonate, which is precipitated. The water of Port-au-Prince probably loses its carbon dioxide partly because the temperature of the air, especially during the day, is greater than that of the fresh spring water and partly because it is so greatly aerated in passing through pipes that are only partly full and in tumbling through numerous manholes, in which it is violently agitated. The result is that calcium carbonate is precipitated in aqueducts and water pipes so abundantly and rapidly as to obstruct small pipes seriously in a few years.

Hardness in waters can be treated in several ways. Most of the bicarbonate can be removed by heating, which drives off the excess carbon dioxide and causes the precipitation of calcium carbonate. Filtration to remove the precipitate is necessary if the water is to be used within a few hours. This method of treatment is too expensive for a city supply. Bicarbonate and carbonate hardness can be entirely removed by what is generally known as the zeolite process. By this process the water is forced through a mass of specially prepared sodium-aluminum silicate and its calcium and magnesium are exchanged for sodium. This process also is not well adapted to the treatment of large city supplies.

The commonest method of softening water is that which is known generally as the lime-soda process. The added lime reacts with the bicar-

bonate, converting it all to carbonate and causing most of it to be precipitated. The soda converts other calcium salts, such as sulphate, to carbonate and promotes their precipitation. This precipitate, however, requires many hours, sometimes even days, to settle, and filtration of some kind is usually resorted to instead of complete settling. The process may be either intermittent or continuous. The continuous plants are much more compact but are more difficult to operate successfully. Several such plants in the United States treat successfully from one to five million liters of water a day for industrial use.

No cheap process of softening the water of Port-au-Prince appears to be available. At least two separate plants would be required, one for the combined water of Turgeau and Plaisance springs, the other for the water of Diquini, Chaudeau, and Le Clerc. Large reservoirs would be needed for treating the water and removing the bulk of the precipitate, and filtration through sand would be necessary to remove traces of precipitate that otherwise would be carried over and deposited in the mains as now. The filter beds would require frequent renewal. Such a plant might cost $50,000 to $100,000, and its operation would cost several thousand dollars a year.

As has already been stated (p. 575), the present distributing system is much to blame for the formation of the precipitate; if it could be repaired so that the water would be kept under pressure in air-tight mains not nearly so much precipitate would be formed.

Although the softening of the entire supply of Port-au-Prince does not seem practicable, the softening not only of the water of that city but of most other waters of the Republic on a small scale for use in steam boilers, laundries, and other industrial plants would probably be economical. Many firms make a special business of installing effective plants for such treatment of water. For small steam boilers the use of suitable boiler compounds or the simple addition of a little sodium carbonate to the feed water would be helpful. This treatment does not prevent precipitation in boilers, but the precipitated material can usually be blown out before it forms scale.

Surface Water.

Tippenhauer[1] has suggested that an adequate surface supply for Port-au-Prince could be obtained by constructing a tunnel to direct the Grande Rivière de Léogane into Rivière Froide at the locality where the two streams are separated by a narrow ridge near Croix Imbert. Probably this scheme is feasible, but it would be very expensive and would involve an entire reconstruction of the present distributing system. Surface water supplies have many advantages, however, and a survey of the project with an estimate of cost might be justified. Measurements of the flow of the

[1] Tippenhauer, L. Gentil, Beiträge zur Geologie Haïtis: Petermanns Mitt., Band 47, p. 177, 1901.

Froide and the Grande Rivière de Léogane, particularly of their minimum flow, should be made over a number of years. River water undoubtedly would be much softer than the present spring supply and would deposit less scale in pipes. The Grande Rivière de Léogane should furnish water of as good or better quality than that of the Grande Rivière du Cul-de-Sac (p. 543), as most of its drainage basin is on basalt. Surface water would require sanitary purification either by filtration or chlorination. Filtration would be preferable and would have the advantage of removing some of the hardness.

Conclusions as to Port-au-Prince Supply.

Two courses are open for the improvement of the water supply of Port-au-Prince. One is to discard the present system and to substitute surface water from Rivière Froide or Grande Rivière de Léogane. Such a supply would have several advantages, chief among which are—(1) an abundant supply of water capable of expansion to meet the city's growing needs, such as providing for fire protection, sewerage, and irrigation of municipal parks; (2) softer water, which would deposit not nearly so much scale in pipes. Unfortunately, the cost of installation would be great and the city probably cannot afford it for a long time.

The other course, therefore, and the one that is much more likely to be followed, is to continue with the present system, improving it piecemeal as funds and other circumstances permit. Such new springs as can be appropriated should be added to the system and efforts to increase the flow of those now used should be made if they hold any promise of success. A spring-fed supply will always be subject to seasonal shortages. It should be remembered, however, that a shortage of water may be more apparent than real. If all leaks in the system were stopped, if waste were discouraged by metering the water to private consumers,[1] and if storage for the surplus night flow could be provided the city should have abundant water compared to what it has had. A spring-fed gravity system has certain advantages. The intake works are inexpensive and the conduits are easy to maintain. The present system also has the advantage of being already in operation. For these reasons it is likely to remain for some time.

CAP-HAÏTIEN.

Purpose of Investigation.

The water supply of Cap-Haïtien, like that of Port-au-Prince, is inadequate, especially in dry seasons. Late in February, 1921, several days were spent in a study of the geology in the vicinity of the city with reference to its water supply, and in April, 1921, a preliminary report was

[1] The initiation of some equitable plan for making the charges proportional to the quantity of water used is recommended in the Rapport de l'Ingénieur en Chef, 1920-1921, Port-au-Prince.

submitted to the Engineer in Chief setting forth possible ways in which the supply might be supplemented. The present report does not differ materially from the preliminary report. Some statements have been modified by late information and others have been altered to conform with the plan of the full report. In April, 1919, Conard[1] submitted to the Engineer in Chief a brief report on the water supply of Cap-Haïtien, from which some statements have been taken in regard to the distribution system and the quantity of water used.

Principal Features of Present Supply.

Cap-Haïtien stands on a very narrow alluvial plain that lies between the sea and a high, irregularly shaped mountain called the Morne du Cap. The public water supply is obtained from many small springs on the lower slopes of this mountain. The location of the springs, aqueducts, and reservoirs with reference to the city is shown in Figure 37. Almost all the springs now in use except Source Belair were developed carefully and utilized by the French colonists. The openings of the springs were cleaned out, generally to bedrock, and covered with massive housings of stone masonry. The water was conducted in large covered conduits to two masonry reservoirs that stand a considerable distance apart at the foot of the mountain west of the city. This part of the system is unchanged except for minor repairs. From the reservoirs water is distributed by a system of iron water mains installed in the later days of the Republic. A considerable number of private taps serve those who are well to do, but most of the patrons depend on public fountains.

The two reservoirs, known respectively as the Réservoir Justinien and the Réservoir Belair, are sunk flush with the surface of the ground and covered with masonry in six long parallel arches supported by columns. Their capacity as measured by the Hydraulic Service is a little more than 800,000 liters each.

The reservoirs are said to be capable of storing the full 24-hour flow of their respective feeders in normal times, but this statement appears to be a little dubious, for the flow of the springs supplying Justinien must be much greater, probably several times as large, as that of the springs supplying Belair. The statement would indicate a normal daily consumption of about 1,600,000 liters, which, for a population of 20,000, would be about 80 liters per capita a day, or only a little more than half the per capita consumption at Port-au-Prince, which is inadequately supplied. For other reasons the disparity is evidently not so great as the figures would indicate. The aqueduct and pipe lines at the cape appear to be in much better condition, so that the leakage is smaller than at Port-au-Prince, and the reservoirs aid greatly in conserving surplus water that

[1] Conard, R. A., Report from Dept. Eng. of North and Northwest to Engineer in Chief on Water Supply of Cap Haïtien, April 2, 1919. Manuscript on file in office of Engineer in Chief, Port-au-Prince.

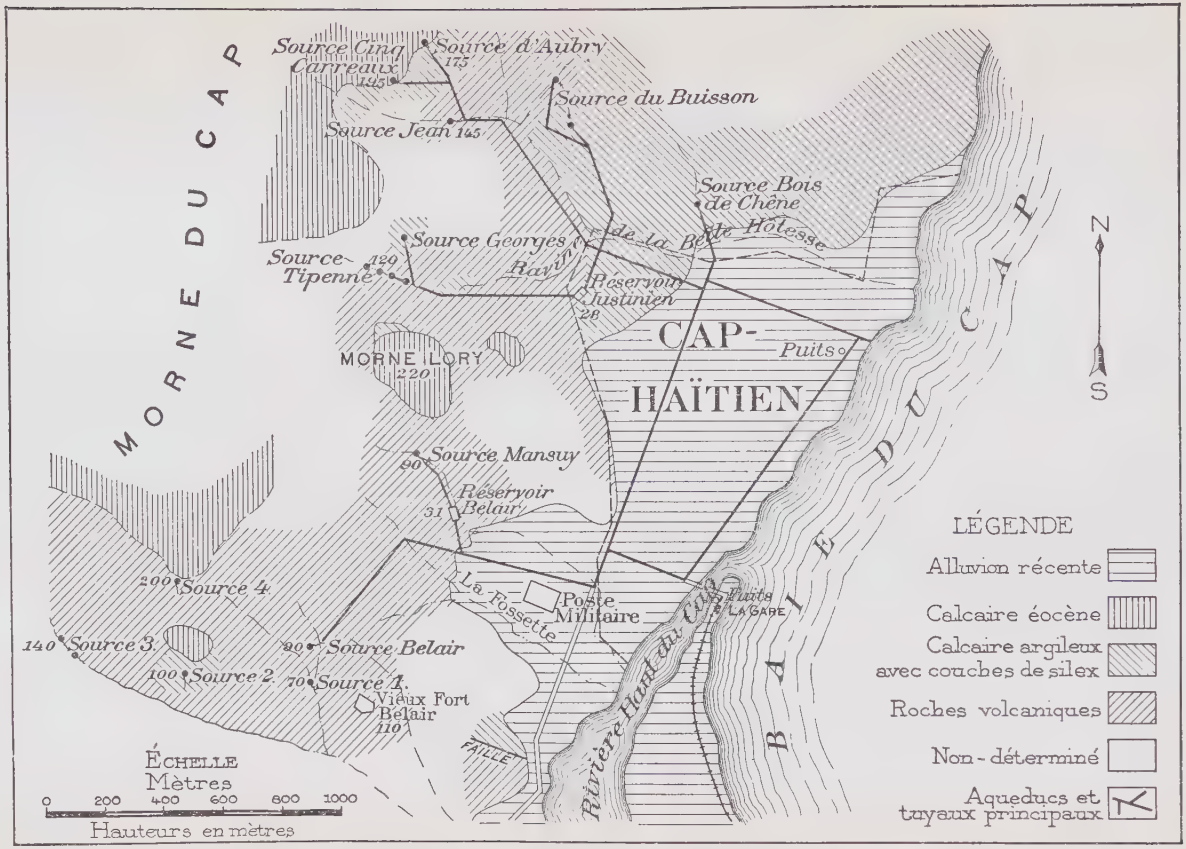


FIGURE 37.—Sketch map showing the water supply of Cap-Haïtien and its relation to the geology.

otherwise would be wasted. Besides, the practice of tapping off the water to private consumers at open manholes is probably not followed. The aqueducts are shorter so that maintenance is easier, and they are so large that there is no danger of their running full under pressure. Most of the iron mains are capable of bearing the pressure from the reservoirs, whose altitude above the town is not great.

The demands on the public supply are greatly lessened, moreover, by the use of shallow dug wells, on which nearly half the population depend. Conard [1] estimated there were 1,000 such wells in 1919. This fact is deplorable, for there are no sewers in the town and ordinary earth privies are used everywhere, so that the shallow water must be extremely unsanitary for drinking, for which it is undoubtedly used by many of the people.

The greatest defect in the water supply at Cap-Haïtien, as at Port-au-Prince, is the wide fluctuation in the flow of springs. Conard [2] estimated the minimum yield of the springs at less than 400,000 liters a day, or about one-fourth of the normal yield in wet seasons. In the winter of 1919-1920 many of the smaller springs were absolutely dry and the flow of the others was greatly diminished. To offset the deficiency a pump was placed in a shallow well near the water front in the heart of the city (Fig. 37), and for several months about 265,000 liters of water is said to have been thus pumped daily into the downtown mains.

The quality of Cap-Haïtien water is indicated by an analysis of a sample from the Réservoir Justinien, given on page 543. The water is comparatively low in total solids, of which calcium and magnesium bicarbonates, or common hardness, is the principal feature. It is chemically satisfactory, except that the minerals it contains tend to form incrustations in pipes or boiler tubes here, as at Port-au-Prince. (For a discussion of possible treatment for hardness see pp. 575-576.)

Geologic Features and their Relation to Water Supply.

ROCK FORMATIONS.

Groups distinguished.—For the purposes of this description four groups of rocks are distinguished in the vicinity of Cap-Haïtien, all of which are shown in Figure 37. The formations exposed in the Morne du Cap are volcanic rocks, probably of Cretaceous age; an impure clayey limestone that includes many beds of pure chert, also probably of Cretaceous age; and a pure white limestone, of upper Eocene age. In addition, Recent alluvium underlies the narrow plain on which the city stands and extends southward onto the North Plain, where it covers a large area (Pl. I).

Igneous rocks.—The igneous rocks may be divided into at least two series. One series consists of a dark basaltic rock, which is probably the oldest rock in the region. The other series comprises porphyritic rocks

[1] Idem. [2] Idem.

of varying texture, which appear to be at least in part intrusive into the other volcanic rocks and into the impure Cretaceous limestone. In their bearing on water supply, however, they may be treated as a unit, and no attempt is made to distinguish them in Figure 37. Both rocks usually are brown or reddish on exposed surfaces. Unweathered specimens of the porphyry are dense and black except for clear crystals of quartz or light colored crystals of feldspar. Near the surface the igneous rocks have disintegrated, leaving a deep mantle of soil on the hillsides. Beneath this mantle they are jointed, so that they break out in irregular blocks. Volcanic rocks are widely exposed around the base of the Morne du Cap, west of Cap-Haïtien, beneath the younger limestones. The southern half of the quarry worked for road metal at the gateway south of the city is in igneous rock. Good exposures were seen also in the ravine below Sources Tipenne.

Impure limestone and chert probably of Cretaceous age.—The impure limestone, which is probably of Cretaceous age, overlies the igneous rocks in small patches west of the city and crops out extensively north of it at the base of the low spur of the Morne du Cap that is generally known as the Morne de la Vigie. It consists of beds of brown or yellowish impure clayey limestone, beds of black or bluish hard, splintery chert, and a few beds of dark sandstone and conglomerate containing fragments of igneous rock, probably the older volcanic rock. The cherty beds are the most distinctive feature of the formation. They are well exposed along the trail, on the beach north of Carenage, and on the hill just west of the Gendarmerie barracks. The beds of impure limestone are well exposed at Source Georges and near Sources Tipenne and Source Cinq Carreaux. Cherty beds are exposed also at the north end of the road-metal quarry south of the city near the city gate, where they are faulted into contact with porphyry. These rocks are minutely jointed and break up into very small angular blocks. On weathering they yield a rather clayey soil full of fragments of chert.

Upper Eocene limestone.—The upper Eocene limestone is a massive pure white limestone, gray and iron-stained on some weathered surfaces. It covers the higher part of the Morne du Cap and crops out in small patches on the lower slopes and foothills. The limestone is very soluble and loose blocks of it are honeycombed by pits due to solution. It contains underground caverns and solution channels which reduce it at places to a confused mass of huge, loose blocks. The upper Eocene limestone overlies the older, impure limestone and the volcanic rocks, and at the contact between them there is a basal conglomerate composed of pebbles of the older rocks. This conglomerate was seen around Source d'Aubry. Collections of fossil Foraminifera made at several places show that this limestone is of upper Eocene age.

Recent alluvium.—Most of the narrow plain on which Cap-Haïtien is built consists of Recent alluvium washed down from the adjacent moun-

tains. It varies in texture from coarse gravel or boulders down to fine sand or sandy clay. Its maximum thickness along the water front is probably not more than 200 feet and may be even less. It is very thin or even absent on the western part of the plain, where the bedrock, consisting of impure limestone and chert, crops out. Such outcrops may be seen north and west of the Place d'Armes along the city streets and in the Ravine de la Belle Hôtesse.

This alluvial plain at Cap-Haïtien is a narrow projection of the large alluvial area of the North Plain (Pl. I), which in the region south and east of the Morne du Cap attains a width of 10 or 12 kilometers. The alluvium on the North Plain is finer textured than that in the city of Cap-Haïtien. Good brick clay is found at the Laroche brick factory, 2 or 3 kilometers south of the city. Probably the alluvium is thicker on the larger plain. Presumably all the alluvium rests upon bedrock like that which forms the Morne du Cap, probably chiefly igneous rock. Evidence of this fact is found in outcrops of igneous rock in low hills on the North Plain, such as Fort Vilton, Morne Beckly, and Morne Pelle.

Circulation of Ground Water.

Rain falling on the upper Eocene limestone sinks down quickly along open cavities and solution channels. At the base of this limestone its downward flow is checked and it moves laterally along the contact of the limestone with the underlying rock, which is less pervious. At some places it emerges along the contact as springs, such as Cinq Carreaux and d'Aubry. Where they are not too much weathered the impure limestone and the chert rock are rather pervious, containing fractures through which water sinks down to the underlying igneous rocks or at places near the shore to a water table controlled by sea level. The igneous rocks are the least pervious of all, but they absorb some water, though slowly, along cracks and joint planes. The residual soil and the weathered material above the igneous rocks absorb considerable water, which moves laterally along the surface of the unweathered rock beneath and issues as springs at places where outcrops of the bedrock or surface irregularities bring it to the surface. Source Belair and many smaller springs in the rock-floored parts of ravines originate in this way.

The alluvium under the city and in the North Plain doubtless contains a permanent body of ground water. Near the shore the water table stands approximately at sea level, but it rises gradually inland as the altitude increases. This water moves slowly seaward above the underlying bedrock.

Notes on Present Sources of Supply.

The Réservoir Justinien is fed by springs, which rise in several ravines that converge in the northwest part of the city. The largest feeders are Sources Cinq Carreaux, d'Aubry, and Jean.

Source Cinq Carreaux is at the head of a steep ravine filled with great blocks of Eocene limestone, which rests upon the impure limestone and chert. The spring issues at the contact. It is protected by a massive masonry housing. Inside the spring house a trench floored with masonry extends across the ravine, and back of the trench is a stone wall. Behind the wall is an infiltration space filled with rubble, which probably rests on bedrock. Several openings in the stone wall admit water into the collecting trench. This is the typical French colonial method of developing springs and is very effective. Further excavation would not increase the flow of water, which at the time the spring was examined (Feb. 19, 1921) may have been 400 liters a minute. A few weeks before that time it was much less. This is the largest spring utilized in the water system.

Source d'Aubry is only a short distance from Cinq Carreaux, in a small ravine, where the geological conditions are almost the same. The spring emerges at the contact of upper Eocene limestone with the impure limestone and chert formation, and igneous rocks crop out near by. Water issues from a cavern, about 30 centimeters in diameter, in the limestone. The method of development is similar to that at Cinq Carreaux and can not be much improved. The flow of the spring was not more than about one-third that of Cinq Carreaux, and in dry weather it shrinks greatly.

Source Jean is in the bed of a deep ravine. A subsurface flow in gravel and alluvium appears to be brought to the surface by an outcrop of hard volcanic rock in the bed of the ravine. The bedrock surface appears to have been cleaned off carefully and the spring effectively utilized. The yield was perhaps one-third to one-half as great as that of Cinq Carreaux.

Sources Tipenne and Source Georges.—There are four springs, known as the Sources Tipenne, in the ravine back of the Réservoir Justinien and a fifth, called the Source Georges, in a tributary ravine. Each of these springs is at a place where a seepage of ground water in gravel of the ravine bed rises to the surface over ledges of bedrock. All have been developed by cleaning off the bedrock and digging a collecting trench across the ravine and placing behind it a masonry wall with a rubble fill at the rear. The springs are covered by heavy masonry housings and feed into a covered masonry aqueduct about a meter in height. Apparently all the available flow is obtained. The combined yield was not more than 100 or 200 liters a minute, and at times the springs are nearly dry.

Sources Du Buisson and nearby springs.—The name Du Buisson appears to apply to two springs north of the city. The largest is that in the ravine of the same name. It issues from soil and gravel that overlie volcanic rock. Some water appears to be lost by seepage here because the trenching is not deep enough, but the deepening of the excavation and the necessary lowering of the aqueduct would not be warranted, for the observed yield of the spring was only 40 or 50 liters a minute and the amount lost probably is even less.

The other spring consists merely of an excavation in soil on the hillside and yields little water, except in wet seasons. Several of the springs of this type are connected with the aqueduct, but they are not shown in Figure 37. They are practically nothing more than shallow wells or trenches in the smooth soil-covered hillside, and they were all dry when examined in February, 1921.

Source Bois de Chêne is a small spring, probably resembling Source du Buisson. It was not examined.

Source Belair is the principal feeder for the Belair reservoir. It is at the foot of a steep and slightly concave slope between two ravines in an area of volcanic rocks. The bedrock is covered by a deep mass of soil and talus, and the water appears to come from slow seepage in this rubble over the less pervious surface of the unweathered rock below. The spring has been developed by cutting away the hillside and digging a trench about 2 meters deep and 30 meters long parallel to the face of the hill. The trench walls are supported by masonry, and water passes through the wall on the lower side into a covered springhouse and is carried by iron pipe, 10 inches in diameter, to the reservoir. As the trench does not extend down to solid bedrock considerable water is no doubt lost by seepage, which might be saved by deepening the trench to solid rock. This would necessitate lowering the intake. If the depth to rock should be too great to permit convenient lowering of the conduit the water level might be raised to the intake by building a concrete retaining wall on the bedrock along the front of the trench with wings extending up the side of the hill at either end, if necessary. As the Belair spring is the principal feeder for the Belair reservoir and the main dependence of a considerable part of the town, this improvement probably would be justified.

Source Mansuy consists of a seep rising over igneous bedrock in a steep-sided ravine. When examined in February, 1921, it was virtually dry. There seems to be no chance to increase its yield.

Additional springs available.—The French colonists seem not to have overlooked any available springs on the slopes of the Morne du Cap that are adjacent to the city. The surface features and the geology do not suggest any localities favorable for the easy development of an additional supply of water that would flow to the city by gravity. There are, however, a few springs west of Belair in an adjacent drainage basin that could be connected to the Belair pipe line. The names of these springs were not obtained, and they are indicated by numbers on Figure 37. All these springs except No. 3 may be reached by a trail leading nearly westward from a locality between Fort Belair and Belair spring.

Spring No. 1 is on a rolling soil-covered slope a little more than 100 meters south of Belair spring. It was yielding probably 100 liters a minute when examined, not including the flow of two small seeps a little higher up the slope. Perhaps a little more could be obtained by trenching. Unfortunately, this spring lies about 10 or 15 meters lower than the

divide south of Belair spring and could not be connected to the Belair pipe line. It might be carried in a separate pipe line around to the south of the hill on which the old fort stands, but it is doubtful whether the quantity of water obtainable would warrant the expense.

Spring No. 2, the name of which was reported to be Limbère, is about 500 meters west of Source Belair and, according to the aneroid barometer, at least 10 meters higher. If this altitude is correct, the spring could be connected to the Belair pipe line, but a careful survey would be necessary to confirm the altitude. The spring issues on a steep hillside from a small body of upper Eocene limestone that appears to overlie some of the impure limestone and chert. The observed flow was probably from 40 to 80 liters a minute and might be increased a little by opening up the outlet.

Spring No. 3 is really a series of springs or seeps in the bed of a deep ravine, which give rise to a small brook that flows for a considerable distance through the principal valley south of Source Belair. The most favorable locality for its utilization is near the head of seepage a little above the crossing of a prominent trail that leads westward up this valley, where the altitude is about 140 meters above sea level. The water should be developed by putting down a water-tight dam across the ravine to bedrock, which crops out at many places. It would probably be advisable also to put in a fill of loose stones above the dam to the head of seepage. The yield of the spring would probably be from 100 to 200 liters a minute.

Spring No. 4 is on the slope directly above Spring No. 2, about 100 meters higher. The spring issues from a deep soil fill on a flat bench, but the water probably comes originally from the contact of upper Eocene limestone and volcanic rock in the ravine above only a few meters distant. A survey by the Hydraulic Service is said to have shown that it would require 800 meters of pipe line to connect this spring directly with Belair. This measurement appears to be considerably greater than the direct distance between the springs, but the difference may be due to difficulties in the terrane. The better plan, if springs 2 and 3 were being developed, would be to run a pipe line directly down the hill to No. 2. The yield obtainable probably would be 100 liters a minute or more. In developing this spring the soil should be deeply trenched, to bedrock if possible.

Well Water.

Wells in the city.

The well that served as a source of an emergency supply in 1921 is in the heart of the city, near the water front. (See Fig. 27.) It formerly supplied water for a soap factory, which has been abandoned. It appears to have been made by driving a 4-inch pipe down into the alluvial sand and gravel and washing out or boring out the dirt inside. It is 5 meters deep and the water in it stood about 1.4 meters below the surface of the ground, which

is here only about 1.5 meters above sea level. About 263,000 liters of water daily, measured in a large steel tank, is said to have been pumped from this well for 3 or 4 months by a small steam pump. The drawdown was considerable, and the pumping is said to have caused a nearby dug well to go completely dry. No saltiness from the sea was noted, however, although the well is only about 45 meters from the shore. Sanitary examination is said to have shown the presence of colon bacilli in this water, and its use is dangerous in view of the very unsanitary condition of the ground in the city.

Wells designed to supplement the present supply of water should be dug or drilled as near the city as possible, to avoid the expense of pumping a long distance. Geologically the most favorable location would be on the alluvial plain near the heart of the city, for most of the ground water from the mountains passes under this plain on its way seaward. Wells anywhere in the thickly inhabited area are out of the question, however, for the water would be too much contaminated. A great deal of sewage and fecal matter is thrown on the ground all over the city and even beyond its limits, and in addition many earthen privies are in use. There is no impervious cover to prevent filtration downward, and percolating water undoubtedly carries polluting material into the ground water beneath the city. Even deep wells carefully cased probably would yield contaminated water if they were pumped heavily.

Two localities for wells near the city might be considered. One is along the valley of the Ravine de la Belle Hôtesse, in the northern part of the city. To avoid pollution, wells would have to be placed almost on the mountain sides. There is one fairly clean spot north of the ravine between the Civil Prison and the Gendarmerie barracks below the Source Bois de Chêne. This spot is far to one side of the valley and is not favorably situated to yield a large volume of water. Any well in this area will strike bedrock (impure limestone and chert) within a few meters of the surface, and probably would have to be drilled. The individual yield of drilled wells is not likely to be very large and will decrease rather than increase with increase in depth beyond 100 or 200 meters, because the water-bearing fractures become smaller with increase of depth. Wells in this locality would therefore have the several disadvantages of hard rock drilling, deep well pumping, inadequate supply, and possibly also unsanitary water.

The other possible location is in the small alluvial valley southwest of the city, in the locality generally known as La Fossette, near the military encampment. In the vicinity of the military encampment and to the west the ground is fairly clean, although the city, immediately to the east, is not. There is a considerable alluvial fill here. The depth to the permanent water level probably is not more than 8 to 15 meters. It is said that water was found at a depth of 5 meters in the northeast corner

of the military encampment. Wells sunk into the alluvium probably would yield more water than deep wells drawing from the underlying bedrock. They probably would not need to be more than 30 meters deep, at least no deeper than the bedrock. Two or three wells about 6 inches in diameter, spaced at intervals of 20 to 40 meters and placed anywhere in or near the southern border of the military encampment, should be sufficient. The water could be pumped readily into Belair reservoir. The drainage basin tributary to the valley is very small and probably would not yield enough water to constitute more than an adjunct to the present supply. As such it is worthy of consideration if no other improvements are attempted.

POSSIBLE YIELD OF WELLS NEAR THE CITY.

Rough measurements on three different maps, none of which are very accurate, indicate that the area drained by the several ravines crossing the little alluvial plain of Cap-Haïtien is about 5 square kilometers. About half of this area lies above and tributary to the springs that now supply the city.

The mean annual rainfall at Cap-Haïtien for 12 years has been about 1,584 millimeters (see p. 50). On the areas of upper Eocene limestone a large quantity of water is absorbed in caverns in the rocks, but the limestone areas are very small, constituting only the higher summits and a few outlying patches. The other rock formations are less porous, and the clayey soils by which they generally are covered favor a greater run-off, perhaps as much as 50 per cent. Everywhere considerable water is lost by evaporation or dissipated by plant growth.

The proportion of the rainfall that becomes ground water therefore probably does not exceed one-fourth to one-half. Not nearly all of this could be obtained, even by an elaborate system of wells. Possibly as much as one-fifth of the total rainfall might be developed effectively. This would be 317 millimeters per annum. Allowing the full area of 5 square kilometers it would amount to 1,585,000 cubic meters of water, or a supply of 4,340,000 liters daily. This includes polluted water from the surface of the city. The small valley at La Fossette has a drainage area of not much more than one square kilometer and, according to the above calculations, might yield about 900,000 liters daily.

The present yield of the springs must be deducted from any estimate of the quantity of water available for wells, for it represents developed ground water. The total flow appropriated probably averages about 1,200,000 liters daily. Only a small fraction of this amount is to be deducted from the estimate of water available in La Fossette.

WELLS ON THE NORTH PLAIN.

An unlimited supply of well water could be obtained on the North Plain at a distance of 4 or 5 kilometers from the city. This region

receives the drainage from a large area of mountain and plain to the south and there is undoubtedly a great body of fresh ground water beneath it. Flowing water under very low pressure might perhaps be obtained (see pp. 538-539), but the flows are not likely to be large and pumping would certainly be necessary to bring the water to the city.

That part of the North Plain nearest the city is not a suitable place for wells because, with the exception of a narrow sand bar between the river and the sea, it is a salt marsh and is flooded at high tide. Deep wells for a large pumping plant would have to be drilled south of the marshes, at a safe distance from salt water. Any place 100 or 200 meters from the salt marshes would be satisfactory, for the salt water covers this area only a part of the time and the quantity of fresh ground water seeping seaward is great enough to prevent an ingress of salt water unless the wells were pumped very rapidly, much more rapidly than will ever be necessary to supply abundant water for Cap-Haïtien. Probably the best location for wells is south of the salt marshes and east of Rivière Haut du Cap. If it is highly undesirable to cross the river, however, a fairly good location could be found farther west, between the road and the river, in the vicinity of the Laroche estate. Unfortunately, both of these locations are 3 or 4 kilometers from the city gate, but they appear to be the best available.

It should be easy to drill wells on the plain, for the alluvium is soft. The maximum depth to which it would be necessary to drill is probably 150 meters, and bedrock may be reached at less depth. To obtain large yields the wells should be at least 6 inches in diameter, and the casings should be perforated at all good water-bearing horizons. Yields from 500 to 2,000 liters a minute might reasonably be expected, according to the pumping equipment and the amount of drawdown. It is possible that one large well with a deep-well pump would supply all the water needed, but there might be danger, with the great drawdown that would result, of drawing in salt water from the neighboring marshes. It would be better to have a number of wells spaced several meters apart and pumped from a single suction main. At present, probably one or two such wells would furnish all the water needed to supplement the flow of the springs in periods of deficiency. Such a plant could be expanded indefinitely and could even be made the sole source of supply.

Well water from the North Plain should be satisfactory; at least it is not polluted. The plain is thinly settled, especially in the locality suggested for the pumping station, and there are in the alluvium beds sufficiently impervious to prevent any local pollution from extending to the deeper beds.

The only known well that may show the possible value of deep wells on the plain is at the railroad station at Cap-Haïtien (Fig. 37). This well is on the narrow bar that separates the tidal river mouth from the sea, and is at an altitude of less than a meter above sea level. It is only about

60 meters from the bay and 5 meters from the river. The well is 3 inches in diameter and 26 meters deep. It was made by driving a pipe into the ground with a drop-hammer and removing the dirt inside later. According to Mr. Holland, who made the well in 1911, water was struck at 10 meters and rose to the surface. For a time the well flowed slightly. The material penetrated was loam, sand, and gravel, successively. This well is the sole supply of the railroad station. Its water is satisfactorily used in locomotive boilers. It is pumped at a maximum rate of about 10,000 liters in 12 hours and the average daily consumption is about 40,000 liters.

An analysis of this water is given on page 544 and is illustrated graphically in Figure 32 (p. 548). The total solids are rather high, and the large proportion of alkali chloride as well as the preponderance of magnesium over calcium strongly suggests that it is contaminated by sea water, which is not surprising. Evidently the water contains also a large quantity of sodium carbonate, which must have resulted from the interaction of sea-water with bicarbonate-bearing ground water. Water from places farther inland would contain less total solids and a good deal more calcium bicarbonate, but should be good for a city supply. The record of this well is encouraging in that it indicates the presence of a large supply of ground water with a little artesian head in the area around the mouth of Rivière Haut du Cap. A large pumping plant at this locality is out of the question, because the water obtained would certainly become badly contaminated by sea water.

Surface Water.

No surface water with gravity head can be obtained nearer to Cap-Haïtien than the mountains south of the North Plain. Conard [1] recommended bringing water from the headwaters of Rivière Haut du Cap, 21 kilometers south of the city. The water probably would require filtration for sanitary purification. It would constitute an ideal supply, but the installation would be very expensive. A pumping plant would be preferable as a measure of temporary relief, but surface water is worthy of careful consideration for a future enlarged supply.

Conclusions as to Cap-Haïtien Supply.

As indicated above, there are four possible ways in which the water supply of Cap-Haïtien can be improved:

First, certain springs could be added to the present supply, and the flow of Belair might be increased a little, thus adding to the present supply by 20 to 25 per cent. This would not remedy the principal defect of the system, however, which is the great seasonal variation in flow. Nevertheless it is a desirable improvement if nothing better can be attempted, for spring water under gravity head is always cheap water.

[1] Op. cit.

Second, the spring flow could be assisted in periods of deficiency by a small pumping plant near the city, preferably one near La Fossette, which is also desirable if nothing else can be done, and could easily be installed to augment the supply obtained from springs.

Third, a large pumping plant in the North Plain could be made to supplement the spring flow or to replace it entirely. The water would probably be of excellent quality, and the only reason for hesitating to adopt this plan is the expense of installation and maintenance.

Fourth, a surface water supply could be brought from some river, probably the Haut du Cap, in the mountains south of the North Plain. This also is an excellent plan, the chief objection being the expense of installation.

Whatever plan may be adopted, it will be desirable to use all or at least some of the springs to supply the higher outlying parts of the city.

NOTES ON WATER SUPPLY OF SOME OTHER TOWNS AND VILLAGES.

Port-de-Paix.—All the drinking water used in Port-de-Paix is carried on burros from Les Trois Rivières, which is at a considerable distance from the city. Some water of poor quality, used for certain domestic purposes, is obtained from shallow wells in the alluvium that underlies the city. In the hills south of Port-de-Paix there is an old colonial reservoir in which water from small mountain streams was impounded and thence led to the city in a masonry conduit. The Gendarmerie post uses a small reservoir located south of the Champs de Mars to store water from a small stream. It is brought to the barracks in an old colonial conduit, but because of pollution is not used for drinking.

The possibility of utilizing any part of the old colonial gravity system was not investigated. It is not likely that valuable artesian flows can be obtained near the city, and the best source for a city supply would probably be Les Trois Rivières. The water would require purification.

Môle St.-Nicolas.—Most of the water used for domestic supply at Môle St.-Nicolas is carried on burros from Rivière du Môle, which disappears in stream gravels about 3 kilometers from the sea south of the town. Frequently the water is collected carelessly at the lowest point of flow, where it is badly polluted by the washing of clothes and by refuse. Water from shallow wells in the small alluvial plain at the city is used to some extent, but it is said to be often brackish, and it is doubtless unsanitary. The town should have an aqueduct to bring water from the locality called La Gorge, on Rivière du Môle. Purification would be desirable, but even without it the water would be greatly preferable to that now in use.

Baie de Henne.—The only water available for domestic use at Baie de Henne comes from a brackish spring that issues from the limestone sea cliff at the southeastern edge of the village. The cliff consists of Qua-

ternary coralliferous limestone and is about 5 meters high. The spring emerges through a solution channel about 0.5 meter in diameter, and the flow probably is as much as 2,000 liters a minute. The outlet of the spring is completely covered at high tide but is exposed at low tide, the tidal range being probably about a meter or more. Water is obtained at low tide, when the outlet is exposed. It has a distinctly brackish taste, but is used without any ill effect by persons and by animals accustomed to its use. It is said that persons not accustomed to the water occasionally suffer slight illness from its use.

An analysis of a very small sample of this water showed that its chloride content is 1,048 parts per million. This high salinity is due to the admixture of a small quantity of sea water with the fresh water near the outlet of the spring. A tunnel driven horizontally into the cliff for 10 or 15 meters along the channel of the stream, to get water a little farther from the shore might obtain fresher water.

A small amount of water for irrigation and for domestic use could be obtained from shallow dug wells in the alluvium of the little plain in the rear of Baie de Henne. Pumping probably would not pay, however, unless windmills could be used for power.

Anse Rouge.—There are no streams or springs near Anse Rouge, and the region is too dry even to permit the storage of rainwater. The village depends entirely on water carried by boat from Gonaïves or La Pierre. A deep drilling here would be warranted, for there is some chance of obtaining flowing water, or at least water that would rise within easy pumping distance of the surface. The statements made regarding the Arbre Plain (see p. 535) apply to this place. Fifty or more meters of coralliferous limestone would be penetrated first. Artesian water, if obtained, probably would come from the underlying Miocene sandy marls. A thorough test might involve drilling to a depth of 300 meters. The water might possibly be made salty by original sea water included in the Miocene beds.

Gonaïves.—The water for Gonaïves comes from a large spring in La Pierre ravine, about a kilometer north of the village of the same name, which is on the coast about 10 kilometers west of Gonaïves. The spring is at an altitude of about 110 meters above sea level, at a place where massive brecciated limestone full of solution cavities overlies dense, sheeted chalky limestone. The water emerges at the contact of these rocks in the ravine. The spring has built up below its outlet an enormous deposit of travertine, which constitutes a sort of bench or platform about 100 meters long. The travertine contains abundant imprints of leaves and pieces of preserved wood. The outer edge of the platform is a sheer cliff, about 25 meters high, that drops off to the bed of the ravine, which continues below. A considerable flow of water issues also at the base of this cliff and flows to the sea at La Pierre.

The spring above the platform has been developed by digging out the dirt in the ravine and placing around the pit a masonry wall bearing a sheet-iron roof. The water is carried to Gonaïves in a large cast-iron pipe laid on top of the ground. The flow is probably as much as 1,000 liters a minute.

The yield of the spring appears to be inadequate to supply the needs of Gonaïves, although the insufficiency seems to be due in part to clogging of the pipes by calcareous deposits. An analysis of the water (see p. 543) shows that its chief characteristic is bicarbonate hardness. A temporary deficiency in the supply might be remedied by pumping from the spring below the cliff into the mains above.

St.-Marc.—Water is brought to St.-Marc from springs in the hills east of the city, but neither the source nor the distributing system was examined. Flowing artesian water might perhaps be obtained in or near the city, which stands on a synclinal fold of Miocene rocks. Test wells would have to be 200 or 300 meters deep, and the water obtained might be made salty by connate sea water in the Miocene beds.

Léogane.—As stated on p. 529, artesian flows of low head might be obtained at some places near Léogane and on the lower part of the Léogane Plain. Flowing wells would furnish purer water and probably a larger supply than that now available, which is obtained in part from canals from Rivière Momance and in part from springs in the northern part of the town. No study of the water supply was attempted.

Pestel.—The only drinking water at Pestel is that caught in rain barrels from roofs. In dry seasons the water shortage is often great. On the beach just north of the town there is a brackish spring, which supplies water for some domestic uses but is too salty for drinking. The town is at the end of a deep valley in which there are several sink holes in limestone, which probably represent the course of an underground stream, perhaps the same one that emerges as a brackish spring on the beach. A well drilled in this valley some distance from the sea probably would yield good water. The best locality for obtaining water easily would be in one of the two or three sink holes in the southern part of town, for the depth to water there is least and the chances of tapping the underground channel and getting an abundant supply are best. A well in such a location should be guarded very carefully, however, to keep it clean. A well drilled between the sink holes in the heart of town, about opposite the Gendarmerie barracks, should be equally satisfactory and much safer from contamination. It would probably not need to be more than 30 meters deep.

If wells were used to supply water the cemetery in one of the big sinks south of the town should be abandoned. If burials at this place were discontinued the cemetery should not be a source of danger.

Jérémie.—No examination of the water supply at Jérémie was attempted. The water is obtained from a spring in limestone and is said to be satisfactory. Artesian water can not be obtained at the city and a

surface supply probably could be had only from Grande Rivière. Springs are doubtless preferable if they can supply enough water.

Les Cayes.—The water supply of Les Cayes was not examined but it was very unsatisfactory in 1921. Plans were under consideration in 1922 for the development of a better supply, probably either from a small spring-fed lake on the plain about 5 kilometers north by east from the city, or from the Source Moreau, a large spring that issues from a limestone cavern at the northern edge of the plain near Camp Perrin. Either of these sources doubtless would be a great improvement. As a temporary measure it is reported that a shallow well has been dug on the plain near the city. The water pumped from this well seems to be good, and it has considerably increased the supply.

As suggested on page 530 there is reason to expect that flowing wells can be obtained at Les Cayes and farther west along the coast of the plain. Artesian water might afford a satisfactory city supply at less cost than surface water or spring water.

Jacmel.—Jacmel is in a basin underlain by Pliocene rocks, from which flowing water might be obtained in a small area near the city. Such water, however, might be salty. Test wells should be sunk to a depth of 200 or 250 meters. The present supply of the city is derived from springs.

Saltrou.—Saltrou stands on a small alluvial plain at the rear of which there are high hills of limestone. Along the shore there are deposits of beach sand and shingle that are higher in altitude than the town. Some good water is carried to the town from a small stream several kilometers to the north, in the hills, but most of the water used is obtained from shallow wells in the alluvium in the town. This water is brackish and probably also unsanitary. Wells dug in the alluvium north of the town and farther from the sea would furnish better water.

Grand-Gosier.—The village of Grand-Gosier stands on a rocky limestone coast. The only source of water is a shallow hole on the beach less than 5 meters from the sea. The water is very salty. Along the coast northwest of the village, near the mouth of a ravine, there are several springs that yield a large flow of salty water. This ground water could be tapped by digging shallow wells in the ravine farther inland, at least 60 meters from the coast, where it probably would be fresh.

NOTES ON WATER POWER AND DAM SITES.

Considerable water power could be developed in the Republic, but accurate maps and reliable figures showing stream-flow are needed as a basis for any operations. Stream gaging on the larger streams should be undertaken at the earliest opportunity.

Northeastern part.—The mountains of the northeastern part of the Republic, from Grande-Rivière du Nord to the Dominican border, are composed of igneous rocks that would hold water at almost any site where

a dam could be placed on bedrock, and such sites are common. Several streams in the area would supply power.

Plaisance Valley.—Most of Plaisance Valley is underlain by impervious argillite, and a dam built at nearly any locality where the surface features are favorable should hold water. The principal stream, Les Trois Rivières, is rather large.

West of Pilate, at the place called Laporte, Les Trois Rivières passes through a gorge more than 60 meters deep, which might be a desirable site for a dam. This gorge, however, is cut in Eocene limestone, which might not hold water, though it might become tight enough through silting to afford a good power dam. (See notes on Grande Rivière du Cul-du-Sac below.)

Rivière Artibonite and tributaries.—Power could be developed on some of the larger tributaries of the Artibonite. Rivière Frio and Rivière Samaná at some places flow in cascades over limestone cliffs, but not much storage could be obtained on account of leakage through the porous limestone. A low dam on the Bouyaha in the little body of Oligocene beds and alluvium about 3 kilometers north of St.-Rafaël probably would hold water and afford some power. On some small streams near Saut d'Eau there are very high cascades.

On the Artibonite itself low power dams would probably be successful in the limestone gorge northeast of Mirebalais, but storage would not be practicable on account of leakage. Some cascades are reported in this stretch of the river and rapids occur at several places. Below Mirebalais several sites for low power dams probably could be found at places where the valley has a fill of fine alluvium that would prevent leakage.

Rivière Coupe-à-l'Inde.—The Coupe-à-l'Inde, a few kilometers east of Dessalines, passes through a gorge in limestone where rapids and low cascades are common. Some power could be generated here, but storage of water may not be possible.

Grande Rivière du Cul-de-Sac.—The Grande Rivière du Cul-de-Sac emerges from a deep, narrow gorge at the edge of the mountains about 600 meters upstream from Bassin Général. The sides of the gorge consist of massive limestone that rises in a sheer wall about 25 meters above the stream, and the slope of the sides of the valley above this wall is very steep. At the lower end of the gorge the limestone is massive, but both the overlying and underlying beds are thin-bedded. In the narrowest part of the gorge the limestone dips northward at an angle of 25°. Upstream from the narrowest part of the gorge the underlying thin-bedded limestone crops out and the gorge is wider and not so steep-walled. About 350 meters upstream from the mouth of the gorge the stream flows across the crest of a broken anticlinal arch. Upstream from the crest of this arch the beds dip southward—that is, upstream.

The gorge is a favorable site for the construction of a dam to develop power if the minimum flow of the stream is great enough to warrant its

construction. Leakage would prevent the storage of water. If the dam were constructed in vertical stages, silting might effectively prevent leakage and the level of the stream could probably eventually be raised to the desired altitude. Most of the water that would escape downward along solution channels along the northward-dipping bedding planes in the lower part of the gorge, above the level of effective silting, would probably again collect in the stream above the present diversion dam at Bassin Général.

Grande Rivière de Léogane.—South of the Léogane Plain the Grande Rivière de Léogane flows westward along the contact between limestone on the north and basaltic volcanic rocks on the south. This contact is apparently a fault. A favorable site for the construction of a diversion dam is available at the southern edge of the plain, but such a dam would extend across the probable fault, and as it is not known whether the fault is dead slight movements along the fault plane would injure or even destroy the dam. A small amount of water could also be stored, as it seems that the alluvial fill along the stream is thick enough to prevent leakage through the fault zone or through the limestone on the north side of the valley.

Farther upstream, southeastward, the river flows entirely in limestone, and a storage dam there would be impracticable. Still farther southeast the valley is in the large area of basalt in the central western part of the Massif de la Selle. If the valley is wide enough in the area of basalt a storage dam might be built there and a diversion dam in the lower part of the valley.

Grande Rivière de Jérémie.—About 10 kilometers from Jérémie, on the road to Moron, the Grande Rivière de Jérémie passes through a narrow gap in a low range of hills. The place looks favorable for a dam site with large storage capacity. The hills, however, are composed, at least in part, of beds of sand and gravel of Miocene age, which dip northward, and the dam might leak. The place should be more carefully examined.

Farther south, around the Sources Chaudes, good dam sites in basalt could be found. There are also high cascades in some of the small streams. This region, however, is very inaccessible.

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LÜTGENS, RUDOLF, Land, Leute, Reisen in der Republik Haïti: Gesell. Erkunde Berlin Zeitschr., 1914, pp. 771-780.

Brief account of a trip in the Northwest Peninsula; general observations concerning products, routes of travel, and population.

——— Geographische und geologische Beobachtungen in Nordwest-Haïti: Geog. Gesell. in Hamburg Mitt., Band 32, pp. 41-90, 1 map, 3 pls., 10 figs., 1919.

Description of geographic and geologic features of western part of Northwest Peninsula. The trip was made with Tippenhauer, and the conclusions concerning the geology clearly are Tippenhauer's.

MAURY, CARLOTTA J., On the correlation of Porto Rican Tertiary formations with other Antillean and mainland horizons: Am. Jour. Sci., 4th ser., vol. 48, pp. 209-215, 1919.

Contains attempt to correlate some of the Porto Rican Tertiary formations with those of the Central Plain as given by Jones, 1918.

MILLER, GERRIT S., jr., Remains of mammals from caves in the Republic of Haiti: Smithsonian Misc. Coll., vol. 74, No. 3, 8 pp., 1922.

Describes remains of rodents and ground sloths, including two new genera of rodents, collected during the reconnaissance from caves near St.-Michel de l'Atalaye.

MOREAU DE JONNÈS, ALEXANDRE, Histoire physique des Antilles françaises, savoir, La Martinique et les îles de la Guadeloupe, vol. 1, 560 pp., Paris, 1822.

Contains some information on the geology and geography of the Republic, based principally on Moreau de St. Méry. (See pp. 125-126; table, p. 155.) List of earthquakes, 1530 to 1821 (pp. 110-115) and of hurricanes in the West Indies, 1495 to 1821 (pp. 386-393).

MOREAU DE SAINT-MÉRY, M. L. E., A topographical and political description of the Spanish part of Saint Domingo, translated from the French by William Cobbett, 2 vols.; vol. 1, 314 pp.; vol. 2, 318 pp.; Philadelphia, 1796.

The French edition, published at Philadelphia in the same year, was not seen. Contains description of geographic features of the Central Plain, which during the colonial period belonged to the Spanish colony.

——— Description topographique, physique, civile, politique et historique de la partie française de l'isle Saint-Domingue, 2 vols.: vol. 1, 788 pp., 2 map; vol. 2, 856 pp.; Philadelphia, 1797-1798.

An exhaustive treatise describing the colony parish by parish before the revolution. Aside from historical interest, it contains a great deal of valuable geographic information.

[MÜLLER, L.,] Erdbeben in Haiti: Zeitschr. allg. Erdkunde, Neue Folge, Band 8, pp. 509-511, 1860.

Describes effects near Les Cayes of earthquake of April 8, 1860, and discusses aftershocks and additional shocks between April 8 and May 5.

PETERMANN, A., Karte der Insel Haiti: Petermanns Mitt., Band 20, pl. 17, 1874. Scale, 1: 1,100,000. (See also KOFFMAHN, O.)

PIACENTENI, R., De Thomazeau aux Grands-Bois: Observatoire Météorologique du Séminaire-Collège St.-Martial Bull. semest., Jan.-June, 1913, pp. 63-67, 1913.

Interesting account of trip from Thomazeau to Cornillon. Contains descriptions of geographic and geologic features.

PILSBRY, HENRY A., A new Haitian Oligocene [Miocene] horizon: Acad. Nat. Sci. Philadelphia Proc., vol. 62, pp. 487-489, 2 figs., 1910.

Describes and figures three Miocene mollusks from the Central Plain, namely, *Potamides roumaini* Pilsbry, n. sp.; *Potamides caobasensis* Pilsbry, n. sp.; *Arca websteri* Pilsbry, n. sp. (not figured).

——— Revision of W. M. Gabb's Tertiary Mollusca of Santo Domingo: Acad. Nat. Sci. Philadelphia Proc., vol. 73, pp. 305-435, pls. 16-47, 48 text figs., 1922.

Figures *Arca chiriquiensis websteri* Pilsbry (pl. 41, fig. 4), and *Ostrea bolus* Pilsbry and Johnson (pl. 43, figs. 2, 3), previously described from Miocene beds in the Central Plain.

——— Miocene Cirripedia from the Republic of Haiti: U. S. Nat. Mus. Proc. (Awaiting publication.)

Describes and figures Miocene barnacles collected during the reconnaissance, including *Balanus concavus esepatus* n. subsp., and *Balanus polyporus* n. sp.

PILSBRY, HENRY A., and BROWN, AMOS P., Oligocene [Miocene] fossils from the neighborhood of Cartagena, Colombia, with notes on Haitian species: Acad. Nat. Sci. Philadelphia Proc., vol. 69, pp. 32-41, pls. 5, 6, 1917.

Describes and figures two species collected from Miocene beds in the Central Plain, namely, *Turritella calostemma* Pilsbry and Brown, n. sp.; *Ostrea cahobasensis* Pilsbry and Brown, n. sp.

PILSBRY, H. A., and JOHNSON, C. W., New Mollusca of the Santo Domingan Oligocene [Miocene]: Acad. Nat. Sci. Philadelphia Proc., vol. 69, pp. 150-202, 1917.

Describes *Ostrea bolus* Pilsbry and Brown, n. sp., collected from Miocene beds in the Central Plain.

POEY Y AGUIRRE, ANDRÈS, Catalogue chronologique des tremblements de terre ressentis dans les Indes Occidentals de 1530 à 1858; suivi d'une bibliographie séismique concernant les travaux relatifs au tremblements de terre des Antilles, 76 pp., Versailles, 1858. (Extrait de l'annuaire de la Société Météorologique de France, vol. 5, p. 75, séance du 12 mai, 1857.)

RATHBUN, MARY J., Fossil crabs from the Republic of Haiti: U. S. Nat. Mus. Proc., vol. 63, art. 9, 6 pp., 2 pls., 1923.

Describes and figures middle Eocene, Miocene, and Quaternary crabs collected during the reconnaissance, including a new species, *Portunus (Portunus) haitensis*.

RECLUS, ÉLISÉE, The earth and its inhabitants, edited by A. H. Keane, 19 vols., New York, 1886-1895.

Description of island of Haiti in North America, vol. 2, pp. 396-422, 1891.

RITTER, KARL, Naturhistorische Reise nach der westindlichen Insel Hayti, 206 pp., 6 maps, 3 pls., Stuttgart, 1836.

Account of travels in the Republic of Haiti in 1820. Contains geographic information.

ROTH, H. LING, Bibliography and cartography of Hispaniola: Royal Geog. Soc. Supp. Papers, vol. 2, pp. 41-97, 1889.

Valuable annotated bibliography.

ROUZIER, S., Dictionnaire géographique et administratif universel d'Haïti, vol. 1, 393 pp., 12 maps, 3 pls., 1892; vol. 2, 402 pp., 3 maps, 6 pls. 16 figs.; Paris, 1893.

A very useful geographic dictionary, which we have followed more or less closely in the spelling of place names. The third volume was never issued, so that there are no articles farther in the alphabetical list than Haïti. Three-quarters of the second volume is devoted to the article Haïti.

SCHERER, J., Earthquakes in Hayti, April 12 to October 10, 1911: Seismol. Soc. America Bull., vol. 1, p. 171, 1911.

List of shocks for period given in title.

——— Great earthquakes in the Island of Haiti: Seismol. Soc. America Bull., vol. 2, pp. 161-180, map, 1912.

Translation of article published in the Bulletin de l'Observatoire Météorologique du Séminaire-Collège St. Martial, July-Dec. 1911, pp. 153-162, 1912. (See below.)

——— Notes on remarkable earthquake sounds in Haiti: Seismol. Soc. America Bull., vol. 2, pp. 230-232, 1912.

Description of peculiar sounds often accompanying earthquakes in the Republic; called the "gouffre" or the "bruit du gouffre." Many of the bulletins of the Observatoire Météorologique du Séminaire-Collège St.-Martial contain information concerning the gouffre.

——— Le cyclone du 12 août 1915 dans la République d'Haïti: Observatoire Météorologique du Séminaire-Collège St.-Martial Bull. semest., July-Dec., 1915, pp. 154-172, 1915.

Describes the effects of one of the most disastrous hurricanes in the history of the Republic.

——— L'île d'Haïti et le tremblement de terre de Porto Rico (du 11 octobre, 1918): Observatoire Météorologique du Séminaire-Collège St.-Martial Bull. ann., 1918, p. 93, 1919.

Describes effects of this earthquake in the island of Haiti.

[———] Les grands tremblements de terre dans l'île d'Haïti: Observatoire Météorologique du Séminaire-Collège St.-Martial Bull., semest. July-Dec., 1911, pp. 153-162, 1912.

Interesting account of disastrous earthquakes from early colonial period to 1911.

Scherer, J., Les tremblements de terre de l'île d'Haïti dans leur rapports avec le relief du sol et les fosses maritimes qui l'entourent: Observatoire Météorologique du Séminaire-Collège St.-Martial Bull. semest., July-Dec., 1912, pp. 132-139, 1913.

Correlates the seismic phenomena with the geographic and geologic features.

[———] Catalogue chronologique des tremblements de terre ressentis dans l'île d'Haïti de 1551 à 1900: Observatoire Météorologique du Séminaire-Collège St.-Martial Bull. semest., July-Dec., 1913, pp. 147-151, 1914.

Complete catalogue of earthquakes recorded in the island during period given in title.

[———] Tremblements de terre observés en Haïti de l'année 1901-1910: Observatoire Météorologique du Séminaire-Collège St.-Martial Bull. ann. 1920, pp. 100-104, 1921.

Continuation of catalogue published in 1914.

Schomburgk, Sir R. H., Mapa de la Isla de Santo Domingo, Paris, 1858. Scale, 1: 400,000.

Sievers, Wilhelm, Süd- und Mittelamerika, 3d ed., 567 pp., 9 maps, 26 pls., 54 text figs., Leipzig and Vienna, 1914.

Brief description of the island of Haiti, pp. 475-480.

Springer, Frank, A new Tertiary crinoid in the West Indies: U. S. Nat. Mus. Proc. (Awaiting publication.)

Describes Miocene crinoid stems, *Balanocrinus haitensis* n. sp., collected during the reconnaissance.

Stuart, R., Haïti or Hispaniola: Royal Geog. Soc. Jour., vol. 48, pp. 234-274, 1878.

Describes geographic features of the island.

Suess, Eduard, La face de la terre (French translation by Emmanuel de Margerie of Das Antlitz der Erde), 3 vols. and index, 3695 pp., 5 pls., 10 maps, 551 figs., 1905-1918.

Discusses tectonic features of the West Indies in vol. 1, pp. 113-124, 362-369; vol. 3, pp. 1285-1292, 1628.

Taber, Stephen, The great fault troughs of the Antilles: Jour. Geology, vol. 30, pp. 89-114, pl. 1 (map), 1 text fig., 1922.

Contains brief descriptions of the disastrous earthquakes in the island of Haiti and discusses their probable origin.

——— The seismic belt in the Greater Antilles: Seismological Soc. America Bull., vol. 12, pp. 199-219, pl. 7, 1922.

Includes description of disastrous earthquakes in the Republic and discussion of their origin.

Thomasset, Henri, Rapport sur les gisements de charbon de l'Asile et du Camp-Perrin (adressé à Monsieur le Secrétaire d'État des Travaux Publics): Le Moniteur, 53e année, No. 46, pp. 358-359, 8 juin, 1898.

Describes and gives analyses of lignite in the Asile Valley and at Camp Perrin.

——— Sur les mines de cuivres de la Grande-Rivière du Nord: Le Moniteur, 59e année, No. 45, pp. 408-409, 1904.

Describes mineral deposits near Grande-Rivière du Nord.

——— Carte physique et politique de l'île d'Haïti: Port-au-Prince, 1908. Scale, 1: 400,000.

TIPPENHAUER, L. GENTIL, Die Insel Haiti, 693 pp., 21 pls., 23 figs., Leipzig, 1893.

A monograph of the island. Contains a great deal of information concerning the geographic features of the Republic. Discussion of geology (pp. 80-121) based principally on Gabb's report on geology of Dominican Republic, supplemented by Tippenhauer's explorations in Republic of Haiti. Contains catalogue of earthquakes from 1551 to 1890 (pp. 170-175) and an extensive bibliography of all subjects (pp. 672-693).

——— Geologische Studien in Haïti; I, Aus der südwestlichen Halbinsel: Petermans Mitt., Band 45, pp. 25-29, pl. 3 (map), 1899.

Description of geographic and geologic features of region from Miragoâne to Aquin, westward to St.-Louis du Sud, and between Aquin and Anse-à-Veau.

——— Beiträge zur Geologie Haïtis; II, Aus der nordwestlichen Halbinsel: Petermanns Mitt., Band 45, pp. 153-155, pl. 10 (map), 1899.

Description of geographic and geologic features of region between Gonaïves and Gros-Morne, Gros-Morne and Le Borgne, Le Borgne and Port Margot, Port Margot and Plaisance, Plaisance and Gros-Morne.

——— Beiträge zur Geologie Haïtis; III, Geologische Studien zwischen Port-au-Prince, Jacmel, Bainet, und Grand-Goave: Petermanns Mitt., Band 45, pp. 201-204, pl. 13 (map), 2 text figs., 1899.

Description of geographic and geologic features of region given in title.

——— Beiträge zur Geologie Haïtis; IV, Die Erzfundstätten von Terre-Neuve und Gonaïves: Petermanns Mitt., Band 47, pp. 121-127, pl. 10 (map), 2 text figs., 1901.

Description of geographic features, geology, and mineral deposits of Terre-Neuve district.

——— Beiträge zur Geologie Haïtis; V, Das La Selle-Gebirge, die Cul-de-Sac—Ebene, und das Salzeengebiet: Petermanns Mitt., Band 47, pp. 169-178, pls. 13, 14 (maps), 1901.

Description of geographic and geologic features of the Cul-de-Sac Plain, and of the mountains south of the west end of the plain. Contains list of earthquakes from 1890 to 1898 (p. 171).

——— Beiträge zur Geologie Haïtis; VI, Das Lignitlager von Maïssade und der Aufsteig zum Zentralplateau von Gonaïves und von Norden aus: Petermanns Mitt., Band 47, pp. 193-199, pls. 15, 16 (map and sections), 3 text figs., 1901.

Description of geographic and geologic features of northwestern part of the Central Plain; of region between Gonaïves and St.-Michel de l'Atalaye; Gonaïves and Section Paul; St.-Michel de l'Atalaye and Marmalade; St.-Raphaël, Dondon and Grande-Rivière du Nord; Grande Rivière du Nord and Pignon. Describes lignite near Maïssade.

——— Neuer Beitrag zur Topographie, Bevölkerungskunde und Geologie Haïtis: Petermanns Mitt., Band 55, pp. 49-57, pl. 5 (map), 1909.

Description of geographic and geologic features of central part of the Central Plain, of the mountains along the northeast border of the plain from Cerca-Carbajal to Los Pozos, of the mountains along the southwest side of the plain from Morne Bois Rouge to Morne Michel (Morne à Tonnerre), of the Artibonite Valley around Mirebalais, and of the mountains south and southwest of the valley from Section Boucassin to Morne Terre-Rouge.

TRUAN Y LUARD, ALFREDO, and WITT, OTTO N., Die Diatomaceen der Polycystinenkreide von Jérémie in Hayti, Westindien, 24 pp., 7 pls., Berlin, 1888.

Lists 98 species and varieties of fossil diatoms collected in 1873 near Jérémie. Most of the species and varieties, 37 of which are new, are described and figured. Age of beds not given, but it probably is Quaternary.

VAUGHAN, T. WAYLAND, Geologic history of Central America, and the West Indies during Cenozoic time: Geol. Soc. America Bull., vol. 29, pp. 615-630, 1918.

Contains discussion of geographic and tectonic relations of the island of Haiti.

——— The biologic character and geologic correlation of the sedimentary formations of Panama in their relation to the geologic history of Central America and the West Indies: U. S. Nat. Mus. Bull. 103, pp. 547-612, 1919.

Contains discussion of geographic and tectonic relations of the island of Haiti.

——— Correlation of the Tertiary formations of Central America and the West Indies: Bernice P. Bishop Museum Special Pub. 7, pp. 819-844, 1921.

Contains discussion of correlation of some of the Tertiary rocks of the Republic.

VAUGHAN, T. WAYLAND, COOKE, C. WYTHE, CONDIT, D. D., ROSS, C. P., WOODRING, W. P., and CALKINS, F. C., A geological reconnaissance of the Dominican Republic: Dominican Rep. Geol. Survey Mem., vol. 1, 268 pp., 23 pls., Washington, 1921.

Plaisance limestone named on page 58. Two specimens of basalt from crest and north slope of Plaisance Mountain described on page 87.

——— Un reconocimiento geológico de la República Dominicana: República Dominicana Servicio Geológico Mem., vol. 1, 302 pp., 23 pls., Washington, 1922.

Spanish edition of preceding report.

WETMORE, ALEXANDER, Remains of birds from caves in the Republic of Haiti: Smithsonian Misc. Coll., vol. 74, No. 4, 4 pp., 2 text figs., 1922.

Describes and figures remains of birds, including a huge barn owl, *Tyto ostologa* n. sp., collected during the reconnaissance from caves near St.-Michel de l'Atalaye.

WOODRING, WENDELL P., Middle Eocene Foraminifera of the genus *Dictyoconus* from the Republic of Haiti: Washington Acad. Sci. Jour., vol. 12, pp. 244-247, 1922.

Brief notice of discovery of middle Eocene Forminifera remarkably similar to species from the middle Eocene of Egypt.

——— Stratigraphy, structure, and possible oil resources of the Miocene rocks of the Central Plain: Rep. Haiti Geol. Survey, 19 pp., map, 1922.

Preliminary acount of geologic features of the Central Plain.

——— Tectonic features of the Republic of Haiti and their bearing on the geologic history of the West Indies (abstract): Washington Acad. Sci. Jour. (Awaiting publication.)

Abstract of a paper describing tectonic features of the Republic and their bearing on interpretation of the great submerged troughs of the West Indies.

——— An outline of the results of a geological reconnaissance of the Republic of Haiti: Washington Acad. Sci. Jour., vol. 13, pp. 117-129, 1923.

Brief summary of results of the reconnaissance.

——— Tertiary mollusks of the genus *Orthaulax* from the Republic of Haiti, Porto Rico, and Cuba: U. S. Nat. Mus. Proc., vol. 64, art. 1, 12 pp., 2 pls., 1923.

Contains descriptions and figures of unusual specimens of *Orthaulax aguadillensis* Maury collected during the reconnaissance from Miocene beds in the Central Plain.

ANONYMOUS, Copper and iron in Haiti: Min. World, vol. 28, p. 324, 1908.

An optimistic account of the mineral deposits of the Terre-Neuve district.

ANONYMOUS, West Indies Pilot, vol. 1, Bermuda Islands, the Bahama Islands, and the Greater Antilles: U. S. Navy Hydrographic Office Pub. 128, 576 pp., map, 4 text figs., (2d ed.), 1917.

Describes coast and harbors of the Republic (pp. 374-388, 437-479).

The publications in the following list, the titles and notes on which are taken from earlier bibliographies or other sources, as noted under each title, have not been examined. There are many publications describing the colony and the Republic, but in both the following and preceding lists only those are given that are known to contain more than incidental geographic information.

In addition to the publications listed, volume 1 of the Mémoires de la Société Royale des Sciences et Arts du Cap-Français, published at Cap-Français in 1788, contains seven articles on the Eaux de Boynes;[1] five articles on the mineral springs of Mirebalais, Bánica,[2] Bas Moustion, Grande-Anse,[3] and the Montagne Noire (parish of Grande-Rivière du Nord); two articles on the salines of Aquin and the Artibonite;[4] and an article giving the analysis of a copper-bearing rock from Fort Dauphin. (See Cabon, 1916, pp. 164-165.) Most of these articles are mentioned by Moreau de St.-Méry. This society was founded in 1784 under the name Cercle des Philadelphes and was incorporated in 1789 as the Société Royale des Sciences et Arts du Cap-Français. (See Moreau de St.-Méry, vol. 1, pp. 348-352.)

ARDOUIN, BEAUBRUN, Géographie de l'île d'Haïti, précédée du précis et de la date des évènements les plus remarquables de son histoire, 184 pp., Port-au-Prince, 1832.

A later edition in 1856. Description of general geography of the island. From Cabon's bibliographic notes, 1918, p. 124, and Roth's bibliography, p. 45.

BERNARD, BIEN-AIMÉ JEAN, Établissement thermal de Cerca la Source, Paris, 1895.

Report of an official examination of the Sources Chaudes de los Pozos. From Cabon's bibliographic notes, 1918, p. 100.

CHARLEVOIX, PIERRE FRANÇOIS XAVIER DE, Histoire de l'Isle Espagnole ou de Saint-Domingue, 2 vols., Paris, 1730-1731.

Contains detailed descriptions of the Plaine du Nord (Plaine du Cap) and other regions of the early colony. From Cabon's bibliographic notes, 1916, pp. 159-162.

DE GENTON, Essai de minéralogie de l'isle de Saint-Domingue dans la partie françoise: Jour. de Physique, vol. 31, pp. 173-177, 1787.

From Roth's bibliography, p. 58. The title of the periodical probably is "Observations sur la physique, sur l'histoire naturelle et sur les arts, contenant l'abrégé de l'histoire et des mémoires des Académies étrangères de Berlin," etc., later continued under the title "Journal de physique, de chimie et d'histoire naturelle."

DORSINVILLE, LUC, Silhouette de la Gonâve: Bull. de l'agriculture et de l'industrie, 1911.

Contains description of geographic features and water resources. From Cabon's bibliographic notes, 1918, p. 105.

[1] See pp. 558-562 of this report.
[2] See pp. 562-564 of this report.
[3] See pp. 564-566 of this report.
[4] See pp. 509-510 of this report.

Dorvo-Soulastre, Voyage par terre de Santa Domingo, capitale de la partie Espagnole de Saint Domingue, au Cap Français, capitale de la partie Française de la même isle, 407 pp., Paris, 1809.

Contains description of an earthquake at the Cap. From Cabon's bibliographic notes, 1918, p. 201, and Roth's bibliography, p. 54.

Du Tertre, Jean Baptiste, Histoire générale des Ant-Isles habitées par les François, 4 vols., Paris, 1667-1671.

Probably the earliest description of Tortue Island (vol. 2, pp. 30-31). From Cabon's bibliographic notes, 1916, pp. 155-156, and Roth's bibliography, p. 56.

Fortunat, Dantès, Nouvelle géographie de l'île d'Haïti contenant des notions historiques et topographiques sur les autres Antilles, Port-au-Prince, 1888.

From Cabon's bibliographic notes, 1918, p. 124.

Hepburn, R. S. E., Rapport de M. R. S. E. Hepburn, géologue, au général de division François Jean Joseph, Secrétaire d'État au Département de l'Intérieur et de l'Agriculture: Le Moniteur, 16 ° Année, no. 13, 2 mars, 1861.

Describes lignite deposits near l'Asile, Las Gouamas, Anse-à-Veau, Bánica, and Hinche. From Cabon's bibliographic notes, 1918, pp. 98-99.

Hillion, Mgr., Une excursion aux Sources Chaudes de la Grande-Rivière de Jérémie: Bull. Religieux, 1904, no. 8.

From Cabon's bibliographic notes, 1918, p. 100.

Le Ruzic, I., Tournée pastorale; de Torbeck à Jérèmie, de Corail aux Cayes, Les Cayes, 1904.

Contains description of geographic features of regions given in title. From Cabon's bibliographic notes, 1918, p. 105.

[Madiou, T.,] Notions géographiques et historiques à l'usage des écoles primaires et des écoles rurales de la République d'Haïti, 62 pp., Port-au-Prince, 1875.

A later edition in 1887. From Cabon's bibliographic notes, 1918, p. 124.

Nau, Eugène [Several articles on the ore deposits and lignite deposits of the Republic, published in Le Moniteur and La République, 1859 and 1860].

From Cabon's bibliographic notes, 1918, p. 98.

——— Notes sur les Sources Puantes du Cul-de-Sac: La République, 2 ° Année, no. 2.

Description of the Sources Puantes at northwest corner of the Cul-de-Sac Plain. From Cabon's bibliographic notes, 1918, p. 100.

——— [Description of Anse-à-Galets and near-by parts of Gonave Island]: Le République, 2 ° Année, nos. 6, 7.

From Cabon's bibliographic notes, 1918, p. 105.

Nicolson, —, Essai sur l'histoire naturelle de l'Ile de St.-Domingue, 1776.

Contains description of geographic features. From Cabon's bibliographic notes, 1916, pp. 162-163.

Ramsay, Diana, Abrégé de la géographie d'Haïti à l'usage de la jeunesse Haïtienne, 49 pp., Port-au-Prince, 1857.

From Tippenhauer's bibliography, 1893, p. 679.

ROUMAIN, EDMOND, La question des mines en Haïti: Chambre de Commerce française Bull., no. 4, [date?].

Discusses mineral resources of the Republic. From Cabon's bibliographic notes, 1918, p. 99.

ROY, LOUIS, Les mines de cuivre et de fer de Terre-Neuve: Bull. Officiel de l'Instruction Publique, 6 ° Année, nos. 9, 10, [date?].

(From Cabon's bibliographic notes, 1918, p. 99.)

THEBAUD, and JEAN LOUIS, Géographie de l'île d'Haïti, contenant des notices historiques, statistiques, géognostiques, etc., Jacmel, 1886.

From Tippenhauer's bibliography, 1893, p. 680.

TREMBLY, —, Essais hydrauliques pour la Plaine de l'Artibonite, ou Mémoires pour indiques les moyens—1°, d'arroser cette plaine; 2°, de la préserver d'inondation; et 3°, d'empêcher qu'une grande étendue de terres ne soit submergée par les rivières de l'Ester, du Cabeuil et de la Coupe à l'Inde.

From Moreau de St.-Méry, vol. 2, p. 141, 1798.

WAINRIGHT, J. C., JEANNOT, A., and TIPPENHAUER, L. G., Rapport de la Commission chargée d'étudier le tracé d'une ville à la Gonâve, Les Cayes, 1890 [also published in Le Moniteur].

Contains description of geographic and geologic features of Anse-à-Galets and near-by parts of Gonave Island. From Cabon's bibliographic notes, 1918, p. 105.

APPENDIX I.—SOME NEW EOCENE FORAMINIFERA OF THE GENUS DICTYOCONUS.

By Wendell P. Woodring.

The only Foraminifera described in this appendix are the new middle and upper Eocene species of *Dictyoconus* which are figured on Plates IX and XIII as characteristic fossils.

Genus DICTYOCONUS Blanckenhorn.

Blanckenhorn, 1900, Deutsche geol. Gesell. Zeitschr., Band 52, pp. 419, 434.
Type (by monotypy): *Patellina egyptiensis* Chapman. Middle Eocene, Egypt.

Dictyoconus codon Woodring, n. sp.

Plate IX, Figures 1, 2, 5, 6 (p. 104).

Test large, conical, height less than half the diameter at base, sides and base undulated, sides slightly concave, apex broadly rounded, basal angle subacute; on worn specimens a fine network of concentric annuli divided into narrow rectangles is visible at the surface, except on the base; base punctate; in thin section the test is seen to be composed of an outer layer of small tubular chambers open toward the interior, divided by one or two short thin partitions, the interior composed of irregular labyrinthic chambers, imperfectly arranged in concentric annuli convex toward the base.

Dimensions: Diameter at base 8 millimeters, height 2.5 millimeters (type); diameter at base 7.5 millimeters, height 3 millimeters; diameter at base 4.7 millimeters, height 2 millimeters.

Type: U. S. Nat. Mus. Cat. No. 350586.

Type locality: Road from Plaisance to Ennery, at north foot of Mont Puilboreau, about 5 kilometers from Plaisance; altitude 515 meters above sea level (U. S. Geol. Survey station 9857). Other localities: Stations 9888, 9441, 9859, 9860, 9442, and 9734. (For detailed descriptions see pp. 105-106.)

The low conical outline and undulate base are characteristic features of this species. None of the sections show the initial spiral stage. *D. codon* closely resembles *D. egyptiensis* (Chapman),[1] a middle Eocene Egyptian

[1] Chapman, F., On a *Patellina* limestone and another foraminiferal limestone from Egypt: Geol. Mag., new ser., dec. 4, vol. 7, pp. 3-17, pl. 2, 1900. More fully described by C. Schlumberger and Henri Douvillé, Sur deux Foraminifères Éocènes: Soc. géol. France Bull., 4th sér., vol. 5, pp. 291-304, pl. 9, 7 text figs., 1905.

species, but is larger and lower, and has an undulate base. It is confined to the Plaisance limestone. Dr. C. A. Matley, Government geologist of Jamaica, has recently collected the same or a very similar species from the "Yellow limestone" of Jamaica.

Dictyoconus puilboreauensis Woodring, n. sp.

Plate IX, Figures 3-5, 7, 8 (p. 104).

Test medium sized, conical, height between half and two-thirds of diameter at base, sides slightly convex, apex broadly rounded, basal angle obtuse; surface covered with thin vitreous coat, generally worn, revealing narrow concentric annuli divided into narrow rectangles; base punctate; in thin section outer layers of chambers are seen to be small, tubular, open toward the interior, divided by one or two partitions; the interior is composed of irregular labyrinthic chambers arranged in concentric annuli parallel to the base.

Dimensions: Diameter at base 3.8 millimeters, height 2 millimeters, (type); diameter at base 3 millimeters, height 2 millimeters; diameter at base 2.7 millimeters, height 2.5 millimeters.

Type: U. S. Nat. Mus. Cat. No. 350587.

Type locality: Road from Plaisance to Ennery, at north foot of Mount Puilboreau, about 5 kilometers from Plaisance; altitude 515 meters above sea level (U. S. Geol. Survey station 9857). Other localities: Stations 9771, 9888, 9889, 9858, 9441, 9859, 9860, 9442, 9861, 9991, 9871, 9734, 9873 (identification doubtful), 9792, 9753, and 9754. (For detailed description see pp. 105-106.)

One section shows the initial spiral stage (Pl. IX, Fig. 8).

This species was collected in the same beds of the Plaisance limestone as *D. codon,* but it is more abundant and was obtained at more localities. There is a possibility that the two "species" are megalospheric and microspheric forms of the same species. *D. puilboreauensis* is smaller than *D. condon* and higher and has a convex base, but the chambers are very similar. It is smaller and more evenly conical than *D. egyptiensis* (Chapman) and has shorter outer chambers. Dr. Matley's collections show a very similar *Dictyoconus* in the "Yellow limestone" of Jamaica.

Dictyoconus puilboreauensis nannoides Woodring, n. subsp.

Plate XIII, Figures B, C (p. 140).

Test small, conical, height two-thirds or more of diameter at base, sides slightly convex, base decidedly convex, apex broadly rounded, basal angle obtuse; the chambers resemble those of *D. puilboreauensis puilboreauensis,* but the partitions between the outer chambers are slightly longer.

Dimensions: Diameter at base 2 millimeters, height 1.5 millimeters, (type); diameter at base 2.5 millimeters, height 1.8 millimeters; diameter at base 1.5 millimeters; height 1.7 millimeters.

Type: U. S. Nat. Mus. Cat. No. 350588.

Type locality: Cliff about a kilometer south of Dolan, near trail from Terre-Neuve to Gonaïves (U. S. Geol. Survey station 9821). Other localities: Stations 9864, 9925, 9989, 9804, 9869, 9868, 9827, 9735, 9848, 9851, 9865, 9814, 9824, 9816, 9826, 9842, 9796, 9843, 9795, 9964, 9742, 9890, 9883, 9886, 9887, 9789, 9919, 9456, 9914, 9790, and 9517. (For detailed descriptions see pp. 140-145.)

This subspecies, which seems to be characteristic of the upper Eocene (Priabonian) limestones, is smaller than *D. puilboreauensis puilboreauensis,* and the diameter at the base and the height are more nearly equal; it also has slightly longer outer chambers. It resembles *D. americana* (Cushman),[1] an upper Eocene species from the island of St. Bartholomew, but its base is more convex and does not flare out at the peripheral angle; it also has wider and shorter outer chambers.

[1] Cushman, J. A., Fossil Foraminifera from the West Indies: Carnegie Inst. Washington Pub. 291, p. 43, text fig. 3, 1919.

APPENDIX II.—SOME NEW MIDDLE EOCENE AND LOWER MIOCENE MOLLUSKS.

By Wendell P. Woodring and Wendell C. Mansfield.

The only Tertiary mollusks described in this appendix are the new species figured on Plates X and XVI as characteristic fossils.

Genus POTAMIDES Brongniart.

Brongniart, 1810, Annales du Muséum d'Histoire Naturelle, Paris, vol. 15, p. 368.[1]
Type (by monotypy): *Potamides lamarkii* Brongniart. Oligocene, Paris Basin.

Potamides tippenhaueri Woodring and Mansfield, n. sp.

Plate XVI, Figures 3, 4 (p. 192).

Shell medium sized; later whorls bear a shelf-like spiral cord at the suture and two narrower spiral threads below the shelf; narrow arcuate axial ribs nodulate the two spiral threads but merely undulate the shelf-like spiral, and on the body whorl the axials become weaker; on the early whorls the shelf-like spiral is about as strong as the other two spirals and is nodulated like them; base of the body sculptured with prominent narrow spiral threads; aperture of all the specimens imperfect, anterior beak short, curved backward, columella slightly swollen at the edge of the very shallow siphonal canal.

Dimensions: Length 30+ millimeters, width 14 millimeters (type).

Type: U. S. Nat. Mus. Cat. No. 350581.

Type locality: First long bluff on right bank of Rivière Blanche below gorge, bed 43 of section on page 170 (U. S. Geol. Survey station 9725). Other localities: Stations 9711, 9726, 9727, 9728, 9731, 9732, and 9733. (For detailed descriptions see pp. 191-193.)

This is one of the most characteristic mollusks of the Maïssade tongue of the Thomonde formation, particularly on Rivière Blanche. In general features it resembles *P. roumaini* Pilsbry,[2] a Maïssade species (see Pl. XVI, Figs. 1, 2), but adult shells retain the axial sculpture found only on young shells of *P. roumaini*. The name is given for Mr. L. Gentil Tippenhauer of Port-au-Prince.

[1] The genus is defined on page 367, but there it is given the vernacular name *Potamide*.
[2] Pilsbry, H. A., Acad. Nat. Sci. Philadelphia Proc., 1910, p. 487, text fig. 1910; idem, 1921, p. 374, 1922.

Genus CHAMA Linné.

Linné, 1758, Systema Naturae, 10th ed., p. 691.
Type (by subsequent designation, Gray, 1847): *Chama lazarus* Linné. Recent, Indian Ocean.

Chama engonia Woodring and Mansfield, n. sp.

Plate X, Figures 2, 3 (p. 106).

Shell medium sized, inequivalve, the left valve larger, rhomboidal; umbones strongly prosogyrate; the shell substance is almost entirely dissolved from all the specimens, and there is no trace of sculpture; some of the specimens show an obscure attachment area on the left valve; hinge inaccessible.

Dimensions: Length 37 millimeters, height 52 millimeters, diameter (both valves) 34 millimeters (type); length 43 millimeters, height 57 millimeters, diameter (both valves) 33 millimeters (largest specimen).

Type: U. S. Nat. Mus. Cat. No. 350573.

Type locality: Road from Ennery to St.-Michel de l'Atalaye, west slope of Crête Salée, about a kilometer from crest (U. S. Geol. Survey station 9792). Other localities: Stations 9950 and 9952. (For detailed descriptions see p. 106.)

If this species is a *Chama* it has an unusual outline. The apparent absence of sculpture may be due to the almost complete removal of shell substance. On some specimens there is a trace of an elongate left posterior lamella at the hinge margin. In its angular outline *Chama engonia* resembles *C. brimonti* d'Archiac and Haime,[1] an Indian Eocene species described from casts, but it is less quadrate and more inequivalve.

Genus PSEUDOMILTHA Fischer.

Fischer, 1887, Manuel de Conchyliologie, p. 1144.
Type (by monotypy): *Lucina gigantea* Deshayes. Eocene, Paris Basin.

Pseudomiltha haitensis Woodring and Mansfield, n. sp.

Plate X, Figure 1 (p. 106).

Shell large, rounded elliptical, compressed; umbo low; lunule apparently very narrow; sculpture consisting of exaggerated incrementals; ligament internal, long and narrow; hinge inaccessible.

Dimensions: Length 115 millimeters, height 100 millimeters, diameter (both valves) 34 millimeters (type); length 128 millimeters, height 105 millimeters, diameter (both valves) 32 millimeters (largest specimen); length 45 millimeters, height 35 millimeters, diameter (both valves) 16 millimeters (small specimen).

[1] d'Archiac, Le Vicomte, and Haime, Jules, Description des animaux fossiles du groupe Nummulitique de l'Inde, p. 267, pl. 23, fig. 9, Paris, 1853.

Type: U. S. Nat. Mus. Cat. No. 350572.

Type locality: Road from Ennery to St.-Michel de l'Atalaye, west slope of Crête Salée about a kilometer from crest (U. S. Geol. Survey station 9792). Other localities: Stations 9950, 9952, 9861, 9889, and 9894. (For detailed descriptions see pp. 105-106.)

This lucinoid is provisionally placed in the genus *Pseudomiltha*. It has the exterior features of the genotype, although most of the specimens are more elongate and there is no trace of radial sculpture. Some of the specimens, particularly small ones, are more rounded than the type. The specimens are more or less completely covered with a calcareous crust. On several specimens the posterior hinge margin is broken away, revealing the cast of the long, narrow ligament. Other specimens show, where the shell is broken away, obscure radial markings and irregular attachment areas of the mantle impressed on the internal cast. Numerous specimens from stations 9792, 9950, 9952, and 9861 show considerable difference in outline. Some are rounded and almost equilateral; others like the type are more elongate and more inequilateral.

No similar American species has been described, but the same or a very similar species has been collected from the "Yellow limestone" of Jamaica. Dr. C. A. Matley, Government geologist of Jamaica, recently brought to Washington specimens from the parishes of St. James and Trelawney. Most of the Jamaican specimens are internal casts and clearly show the long, narrow anterior muscle scar, but the hinge is obscure.

The type of *Pseudomiltha haitensis* and other inequilateral specimens closely resemble *"Lucina" postalensis* Oppenheim,[1] a species from the middle Eocene beds of Monte Postale, northern Italy; less inequilateral specimens resemble *"Lucina" pseudogigantea* Oppenheim,[2] described from the same locality. Most of the Haitian specimens are less rounded and seem to lack the obscure radial sculpture.

[1] Oppenheim, Paul, Die Eocaenfauna des Monte Postale bei Bolca im Veronesischen: Palaeontographica, Band 43, p. 155, pl. 12, fig, 4, 1896.

[2] Idem, p. 154, pl. 12, fig. 3.

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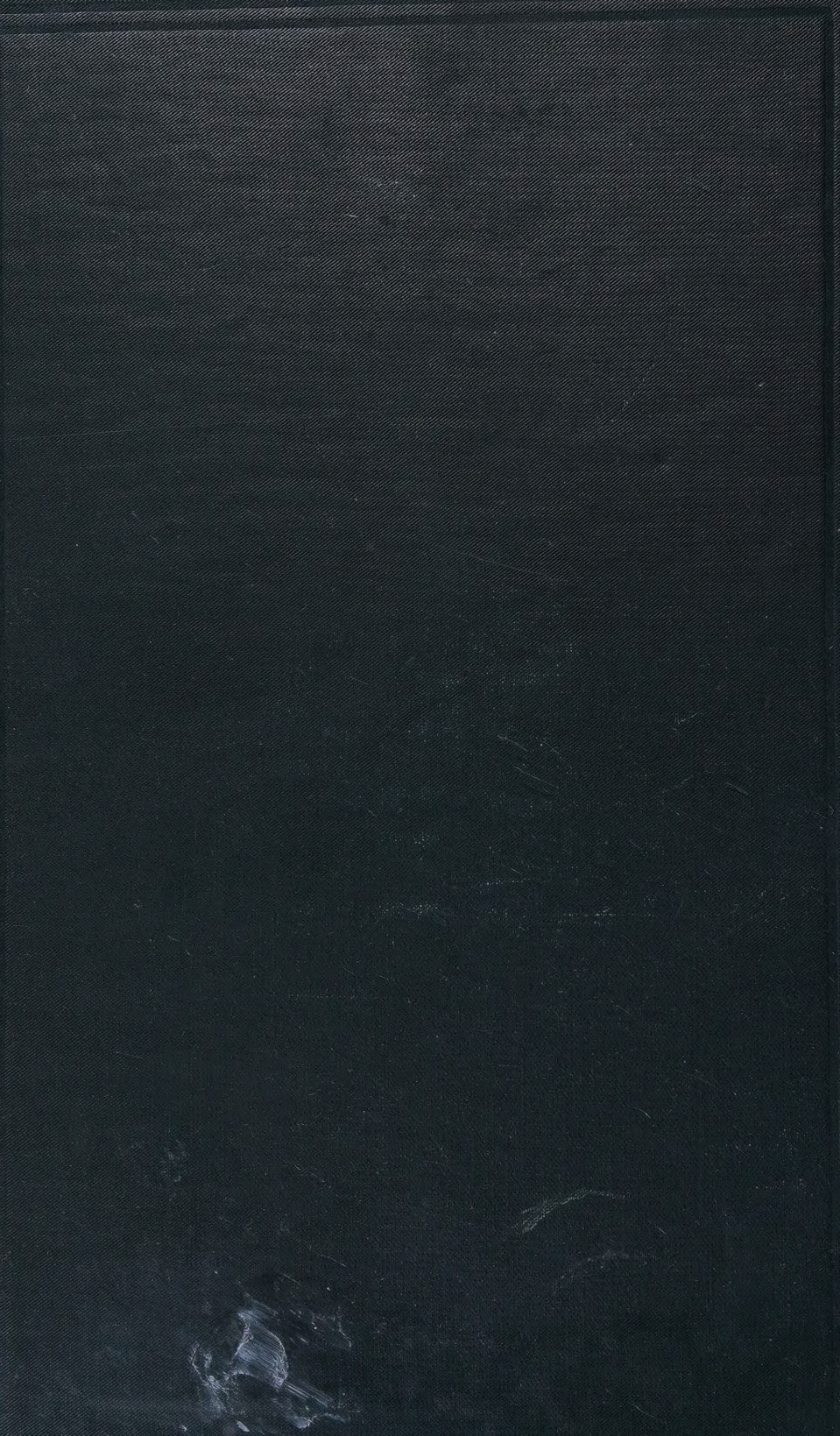
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